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Enviro Control, Inc.
Rockville, MD

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This document comprises the proceedings of the National Seminar on Overland Flow Technology for Municipal Wastewater sponsored by the U.S. Environmental Protection Agency, September 16 through 18, 1980, in Dallas, Texas.

These proceedings include opening statements by Dr. Curtis Harlin, Robert S. Kerr Environmental Research Laboratory, and Mr. Richard Thomas, Construction Grants Program, as co-conveners of the seminar; a welcoming address delivered by Mr. Hendon Crane, Acting Branch Chief, Construction Branch, U.S. EPA - Region VI; a panel discussion with State agency representatives; individually presented papers; and closing remarks by the co-conveners. The papers are reproduced in the order in which they were presented at the seminar. They cover topics including Federal and State policy and guidance, research and development, solids removal, health aspects, design, and case studies of overland flow of municipal wastewater. The papers and panel discussion are followed by questions and answers. The closing remarks summarize the work of the seminar and lead into a showing of the EPA-prepared film Water Passages, structured for public television and featuring basic land treatment, water reuse, and conservation-type systems.

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Introduction

The Clean Water Act of 1977 provided that the U.S. Environmental Protection Agency shall not make grants for publicly owned treatment works under the Construction Grants Program unless the applicant has demonstrated that innovative and alternative treatment processes, including land treatment, have been fully studied and evaluated for use. The Act further provides for certain monetary incentives to encourage the use of these systems. Since the passage of the Act, there has been a dramatic increase in the number of land treatment systems planned and constructed.

Of the three types of land treatment systems, the overland flow system is the least developed but has great potential for use, especially for small cities. Because of its many advantages, including small land requirements and high treatment efficiency, there is a great amount of interest in utilizing the overland flow process. Operating and design experience is limited as yet because there are few operating systems.

With the growing interest in using overland flow, there was a pressing need for dissemination of design and operating information. During the past few years, there has been considerable research of the process, and several notable developmental projects have been operated. These research and developmental projects have resulted in an accumulation of a significant amount of design and operating data. While several reports and journal articles have been published as a result of this work, it was felt that a seminar should be held where all of the available information on the overland flow process could be brought together.

The purpose of the seminar, therefore, was to transfer the latest information on design and operation of overland flow treatment systems for municipal wastewater to the user community. Information from research projects was presented, as well as case histories of operating systems. The end objective was to provide the planner and designer with the best available data which can now be used in applying this technology.

All presentations made during the seminar, as well as condensations of the discussions following, are included in this publication. It is intended to serve as the best available source of design and operating information for the overland flow process until the publication of the revision of the Process Design Manual for Land Treatment of Municipal Wastewater.

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Abstract

This document comprises the proceedings of the National Seminar on Overland Flow Technology for Municipal Wastewater sponsored by the U.S. Environmental Protection Agency, September 16 through 18, 1980, in Dallas, Texas.

These proceedings include opening statements by Dr. Curtis Harlin, Robert S. Kerr Environmental Research Laboratory, and Mr. Richard Thomas, Construction Grants Program, as co-conveners of the seminar; a welcoming address delivered by Mr. Hendon Crane, Acting Branch Chief, Construction Branch, U.S. EPA - Region VI; a panel discussion with State agency representatives; individually presented papers; and closing remarks by the co-conveners. The papers are reproduced in the order in which they were presented at the seminar. They cover topics including Federal and State policy and guidance, research and development, solids removal, health aspects, design, and case studies of overland flow of municipal wastewater. The papers and panel discussion are followed by questions and answers. The closing remarks summarize the work of the seminar and lead into a showing of the EPA-prepared film Water Passages, structured for public television and featuring basic land treatment, water reuse, and conservation-type systems.

Table of Contents

Disclaimer . . . ii
Introduction . . . iii
Abstract . . . v
Table of Contents . . . vi
Welcoming Address
Hendon Crane . . . 1
Overview
Curtis Harlin . . . 3
EPA Policy and Guidance on Overland Flow
Richard E. Thomas . . . 5
State Policy and Guidance on Overland Flow
Jon C. Dyer and Allen Dusault, Jr. . . . 9
Panel Discussion with State Agency Representatives . . . 20
Developmental Research for Overland Flow Technology
Bert E. Bledsoe . . . 30
Overland Flow Treatment of Municipal Lagoon Effluent
C.R. Lee and R.E. Peters . . . 51
Municipal Wastewater Treatment by Overland Flow at Pauls Valley, Oklahoma
Charles H. Lawrence . . . 80
Development of a Rational Basis for the Design and Operation of the Overland Flow Process
Robert G. Smith . . . 100
The Easley, South Carolina, Overland Flow Project
A. Ray Abernathy . . . 172
The EPA Land Treatment Task Force
Richard Duty . . . 183
Removal of Organics by Overland Flow
C. James Martel, John R. Bouzoun, and Thomas F. Jenkins . . . 185
Health Aspects of Overland Flow Treatment
Osman M. Aly . . . 195
Removal of Nitrogen and Phosphorus by Overland Flow
Rashid A. Khalid and William H. Patrick, Jr. . . . 219
Effects of Suspended Solids on Overland Flow Design and Operation
Lloyd H. Ketchum, Jr. . . . 246
Overland Flow Treatment: A Case History at Shafter, California
Richard W. Corneille and Charles E. Pound . . . 251
Case History — Kenbridge, Virginia
D.D. Deemer . . . 272

Overland Flow System: Vinton, Louisiana, Case Study 278
Kelly M. Peil

Overland Flow System Application at Heavener, Oklahoma, for Treatment of Domestic Wastewater 287
Jimmie M. Alford

Overland Flow Design Example 307
D.D. Deemer

Summary and Closing Remarks 316
Curtis Harlin

Summary and Closing Remarks 318
Richard E. Thomas

Welcoming Address

Hendon Crane
Acting Branch Chief, Construction Branch, Region VI
U.S. Environmental Protection Agency

Welcome, ladies, gentlemen, and people of Region VI of EPA to this National Seminar on Overland Flow Technology for Municipal Wastewater.

Overland flow is a viable alternative to conventional treatment systems--a land treatment system that has less documentation and case histories than the slow- or the rapid-rate systems. Hence the element of risk is greater, and because of that risk, overland flow is considered to be innovative technology, although by definition it is an alternative system.

At this time we have some six overland flow projects in the Region, two in Arkansas and four in Louisiana. Allocations for innovative alternative technology (I&A) are based upon 2 percent of the State allocation for Construction Grants for fiscal 1979 and 1980, and 3 percent for 1981. Of these percentages, not less than 0.5 percent must be spent on innovative technology. This is a 10-percent grant to be added to the basic 75-percent grant and must be obligated within 24 months of the appropriate fiscal year allocation.

All of these balances will be reallocated only to States that have already obligated their regular allocation for that particular fiscal year. Should any of this I&A money be lost to reallocation, this effectively bars the State from receiving any further allocation, although that State may have long since exhausted its regular construction grants moneys.

The regional average from the time of award of the Step-One Grant to award of the Step-Three Grant is 29 months, which is 5 months longer than the obligational period for each fiscal year (FY). Construction Grant funds are good for a 2-year period in the year following the end of the fiscal year for which they were appropriated.

Therefore, careful planning is essential in order to expedite these I&A projects, so that timely Step-Two and Step-Three awards can be made without loss of funds. I repeat: Expiring funds are subject to reallocation, thus jeopardizing the Federal funding in the I&A reserves. It is essential, therefore, when an I&A project is in the offing, that a critical path be established at completion of the cost-effective analysis for the project.

This critical path includes the completion of the Step-One award and completion of the Step-Two award, and completion of Step Three. For small communities, 4 percent of the State allocation must be allocated for alternatives to conventional systems, and the obligation period for this reserve is also 24 months. Here are some figures for the mandatory set-asides, the 2 percent for I&A grant increases, and 4 percent for alternative systems for small communities. The total for Region VI for FY 1979 is $12,167,000; for FY 1980, $9.8 million; and for FY 1981, we estimate $13.5 million. The total for that

3-year period, for innovative and alternative technology and 4 percent set aside for small communities, will be almost $35.5 million.

The EPA Region VI has innovative and alternative land treatment coordinators in each State. For Arkansas, the coordinator is Martin Roy. For Louisiana it is Bharat Contractor; for New Mexico, Ed Stokes; for Oklahoma, Charles Newton; for Texas, Milton Rose; and the coordinator for the Region in our Regional Office is Ancil Jones. Each of these men is attending this session to answer questions you might have regarding details of the program, funding, etc.

Let me emphasize that municipal wastewater and overland flow treatment are economic resources. Overland flow recycles and reuses wastewater effectively. The technology can help produce marketable agricultural products, while at the same time removing pollutants. It is a major boost in helping to achieve the objective of the Clean Water Act--that is, achieve the fishable, swimmable goals by 1983, and the no-discharge goal by 1985. We need your help in assuring that the States in Region VI benefit from the allocations that are set aside to the Region for developing and implementing I&A projects for treating wastewater.

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Overview

Curtis Harlin
Chief, Wastewater Management Branch
Robert S. Kerr Environmental Research Laboratory
U.S. Environmental Protection Agency, Ada, OK

The overland flow system is the waste development least developed of the three types of land treatment systems for municipal wastewater. Since the passage of the 1977 amendments of the Clean Water Act, there has been a great amount of interest in the overland flow process. This process has its unique place in land treatment, and it has several advantages where there is a choice of land treatment alternatives. Like other land treatment systems, it is generally low in cost, both in capital cost and operating cost; generally low in energy requirements; it may produce a crop, but this is not normally a major factor; and it is simple to operate.

In addition, the overland flow process is adapted to soil types that may not be suitable for either the slow-rate systems or rapid infiltration systems. Also, land requirements for the overland flow system are less than those for slow-rate systems, which normally would be the other type of land treatment system that the overland flow would compete with.

The Process Design Manual for Land Treatment of Municipal Wastewaters which was published in 1977 had very limited information regarding the design of overland flow systems. Since the publication of this manual, there has been much research and development, which produced a significant amount of data on these systems.

Right now, we are in the process of revising the Design Manual, and we expect it to be completed and distributed by fall of 1981.

Meanwhile, because of the great demand for design information for these systems, a seminar such as this is appropriate to disseminate the latest information in advance of the publication of the new Design Manual.

This seminar has been planned to convey to the planner and to the designer the best currently available information, to be taken back by the attendees and put to use. To accomplish this, the seminar is divided into four phases.

The first phase or group of presentations will deal with summaries of Federal and State attitudes, policies, and regulations. We will see during these presentations a strong Federal endorsement of the overland flow system, as is true for all land treatment systems. We will also see a wide difference among State requirements and regulations for these types of systems.

The second phase will present a series of important research activities in the overland flow development. Intensive research has been underway during the past few years at several locations around the country, producing some very important results. These help us to understand more clearly the processes involved, and thus help us to design these systems with more competence.

The third phase will present several case histories of actual overland flow systems. These presentations will deal with the design of the systems, and, perhaps more importantly, will point out some of the problems that are associated with them. The case histories go into the planning and conception phases of the overland flow systems and can help to provide answers when similar problems arise on the particular projects that you might be involved in.

Finally, all of the current state-of-the-art will be brought together in a presentation of actual design examples. It was felt that this should be the ultimate objective and the primary focus of the seminar. Through the design examples we hope to convey to the planners and designers among you how to apply the information that is available, thus ensuring a successful design of an overland system.

U.S. Environmental Protection Agency Policy and Guidance on Overland Flow

Richard E. Thomas
Municipal Construction Division
U.S. Environmental Protection Agency

PB82-194234

Overland flow is a developing technology for treatment of domestic wastewaters here in the United States. Other speakers at this workshop will point out that research on treating domestic wastewaters in the United States started about nine years ago at the EPA research laboratory in Ada, Oklahoma. There are less than 10 overland flow systems actually operating in the country. All of these operating systems are comparatively new and comparatively small. It is against this background of limited operational experience that the U.S. Environmental Protection Agency (EPA) must establish policy and guidance, which is in agreement with the intent of Federal law to redirect wastewater management from the concept of treatment and discharge to the concept of recycle and reuse.

EPA POLICY

The EPA policy on implementation of land treatment including overland flow was presented in a policy statement issued by the Administrator in October, 1977. Recognizing that progress to implement good land treatment projects had been slower than desired, the policy statement spelled out three major points of emphasis on land treatment of municipal wastewater:

1. The Agency will press vigorously for implementation of land treatment alternatives to reclaim and recycle municipal wastewaters.

2. Rejection of land treatment alternatives shall be supported by a complete justification (reason for rejection shall be well documented in the facilities plan).

3. If the Agency deems the level of preapplication treatment to be unnecessarily stringent, the costs of achieving the excessive level of preapplication treatment will not be considered as eligible for EPA cost sharing when determining the total cost of a project.

The policy statement reiterated the intent of Congress that the Federal Water Pollution Control Act Amendments of 1972 should cause a major shift to recycling and reclamation technologies while stating that the EPA would press vigorously to utilize land treatment. In explaining this position, the policy statement notes that land treatment is capable of achieving treatment levels comparable to the best of the conventional wastewater treatment technologies. Land treatment achieves these levels of treatment with a comparatively low energy demand, because recovery and beneficial reuse of wastewater nutrients through crop production are an integral part of the process in most instances. This policy statement and other EPA guidance, technical reports, and manuals for implementing the Construction Grants Program recognize overland flow as a developing technology that deserves serious consideration in appropriate circumstances.

This policy continues in effect and has been strengthened by the innovative and alternative technology provisions of the Clean Water Act of 1977. In the general case, overland flow is an excellent example of the innovative and alternative technology thrust of the Act. The definition of land treatment in the Act includes overland flow in the category of alternative technology. This makes overland flow eligible for the many financial incentives specific to use of innovative and alternative technology. Among these financial incentives are the following: (1) the Federal share of a construction grant may be increased from 75% to 85%; (2) a requirement to spend 2% of allocated funds on increasing the Federal share from 75% to 85% in fiscal years 1979 and 1980 (in 1981 this set-aside increases to 3%); (3) the Federal Government may participate with full construction grant funding in projects which are up to 15% more costly than the most cost-effective of the conventional alternatives; and (4) projects which fail to meet design criteria may be eligible for 100% Federal grants for modification or replacement. Obviously, the future holds promise for expanding use of overland flow treatment for management of municipal wastewaters.

PRESENT EPA GUIDANCE

The consideration of overland flow in facility planning for projects requesting EPA-administered funds presents a specific and rather unique set of circumstances. As already mentioned, it is a developing technology and there is very little operational experience. Because of this lack of operational experience, State regulatory agencies do not have established criteria and guidance on design and operation. The fact that overland flow shows excellent capability to treat raw sewage presents a further complication. Application of raw sewage to the land is contrary to accepted environmental engineering concepts. The idea of applying raw sewage to the land conjures up the documented health incidents associated with raw sewage farming for food crops to be eaten raw. This practice of irrigating human food crops with raw sewage was justifiably abandoned because of unacceptable health risks. An educational and adjustment period is needed to provide operational experience for establishment of proven criteria and to determine an appropriate match-up of preapplication treatment with the overall objective of specific projects. It is the common dilemma of which comes first--the horse or the cart--and it has led EPA to recommend its position of flexibility for case-by-case determinations. This position allows simultaneous development of proven guidance and adoption of developing technology as mandated by the innovative/alternative provisions of the Clean Water Act of 1977.

Present EPA guidance for preapplication treatment for overland flow is divided into two general levels. The two levels of preapplication treatment recommended recognize proximity of residents in an urban setting as an important factor in site selection. The lesser level of preapplication treatment specifies simple screening or comminution for overland flow in isolated areas without public access. The second level specifies a sufficient level of biological treatment to control odors and nuisance conditions in more urban locations with closer proximity of human habitation.

This EPA decision to recommend screening or comminution as a minimum level of preapplication treatment is based on three sources of information. High strength food-processing wastewaters are successfully treated at many locations in the United States. Removal of the classic pollution parameters as measured by BOD and SS are excellent. There is also a limited amount of long-term results for treatment of municipal wastewaters from Australia and Europe. Treatment of raw municipal wastewater for these facilities is as good as the results for high strength food-processing wastewaters in the United States. Successful treatment of raw sewage at the bench and in field demonstration projects has confirmed the results with food-processing wastewaters in the United States and with domestic sewage in other countries. It is the judgment of EPA that there is a sufficient data base to take an indepth look through the innovative/alternative concepts of the Clean Water Act.

INNOVATIVE/ALTERNATIVE PROVISIONS

The underlying basis of the innovative and alternative guidelines are the monetary provisions established by the Clean Water Act of 1977. The major provision is the grant increase from 75 percent to 85 percent for design and construction of projects which meet specific criteria to recycle resources, recover energy, reduce overall cost, or improve toxics management. Award of 85-percent grants was started as of October 1, 1978 and over 200 projects have qualified for increased grant support. Implementation of the 85-percent grant provision of the Clean Water Act is well underway. Another monetary incentive in the Clean Water Act of 1977 provides for 100-percent grants to modify or replace innovative/alternative features which fail to perform. This is a form of risk insurance to encourage better acceptance of developing technology. The provision to make 100-percent modification or replacement grant awards is as yet to be tested and proven.

There is the usual uncertainty regarding something which has not as yet been put to the test as the time for testing the EPA regulations draws nearer. It should be remembered that the EPA has a firm and basic policy to encourage development of innovative and alternative technologies. Determinations that facilities have not met design performance, or have excessive operating costs and have failed within two years of final inspection will be tested and implemented in the context of this policy. This provision of 100-percent replacement or modification grants is especially important for a developing technology like overland flow. The Agency is aware of this fact, and I want to assure the participants at this workshop that the EPA intends to implement these provisions in the true context of the Agency policy to encourage innovation in wastewater treatment.

SUMMARY

The EPA perspective for overland flow treatment of domestic wastewaters is a position of controlled optimism. Research results and limited operational data identify simplicity, energy savings, and low operating costs as major benefits. Overland flow is a good example of a developing technology which addresses the innovative/alternative aspects of the Clean Water Act of 1977. EPA is encouraging consideration of overland flow in this context on a case-by-case basis at the present time. Workshops such as this one and the continued research evaluation of newly constructed facilities will provide EPA, State agencies, and applicants up-to-date knowledge for improved design and operational reliability. There are small operating systems in Mississippi, South Carolina, Illinois, and New Jersey. In addition, there are some 20 to

30 systems under consideration for future construction and a few systems, mostly in Southern States are under construction now. All of these newly constructed systems should meet the criteria established to determine eligibility for the 100-percent replacement provision of the 1977 Clean Water Act. EPA is confident that overland flow will become a popular and reliable wastewater treatment process. Fortunately, it is uniquely attractive to smaller communities who stand to benefit most from its simplicity and energy saving features.

Question (by Mr. Jeff Sutherland, Williams & Works, Inc., Grand Rapids, MI): You mentioned a State in which the EPA has directed that overland flow treatment be evaluated as a process, but that rapid infiltration need not be, Is there a physical factor or commerical factor related to that?

Response (by Mr. Thomas): It is a siting factor--all of the area is marked out geographically as very heavy soils, i.e., soils that are totally unsuited to rapid infiltration. EPA wanted to put the emphasis on overland flow, which is suited to those soils.

Question (by Mr. Jerry McDermott, Proctor & Gamble Company, Cincinnati, OH): I wondered about the new Design Manual coming out that describes what works and what doesn't work. I wondered how much room there is in the program for variation--for being really innovative and trying different soils and different ways. Can such innovation still get the approval of the grant mechanism?

Response (by Mr. Thomas): Yes, there is a lot of flexibility in the program. If you go out and see the land treatment projects that are being funded, you will have to search a number of them before you find two that are identical. They do vary quite a bit. There is room for a lot of innovation.

For example, we have a silviculture project in the suburbs of Atlanta, which is located in the watershed of its own water supply. This is a large project, and it is actually implementing direct recycle back into its own water supply. In my opinion, that is quite innovative.

PB82-194242

State Policy and Guidance on Overland Flow

Jon C. Dyer, P.E.
Allen Dusault, Jr., Soil Scientist
Environmental Technology Consultants, Inc.
Springfield, Virginia

INTRODUCTION

The 1980's will be a period of time here in the U.S. where costs of wastewater treatment will become a high point of interest to local communities. Capital investments and operation and maintenance costs will be of utmost importance. Local communities are beginning to demand that cost-effective treatment alternatives be considered and utilized, where applicable, in meeting treatment requirements. Land treatment technologies, including overland flow systems, offer cost savings and lower operation and maintenance costs. The trend in State requirements relative to land treatment systems and specifically overland flow, is of a changing and positive nature. EPA's grant assistance program involving the use of innovative/alternative (I/A) technologies and higher (85%) construction grants availability for utilizing I/A technologies has helped impact this effort.

Currently there are over 900 municipal land treatment facilities scattered across the United States. Of these, only a handful are overland flow systems. Twenty years ago, there were only a fraction as many municipal land treatment systems operating and no overland flow systems.

The legal machinery within many States has not been able to keep pace with the increasing interest in land treatment. Some States lack specific regulations or guidelines pertaining to land application of wastewater. Others make reference to land treatment, generally. Only a portion of those States that specifically address land application distinguish between slow-rate, infiltration/percolation, and overland flow systems.

There is a lack of uniform terminology within various States' legal policies. It's common for States to use their own language. Wisconsin, in State "Guidelines for the Design and Construction of Land Disposal Systems" refers to a spray runoff system which is an approximate equivalent to overland flow. Even within the States, there may be a lack of uniform definition of land treatment. The State of New York lists anywhere from 3 to 26 municipal land treatment facilities. The use of different terminology can pose problems when comparing States' policies as well as making it difficult to determine the types and numbers of operating land treatment systems. Adopting a uniform language nationwide would help clarify the situation greatly.

Comparing various States' policies is difficult due to the fact that different agencies and departments can be involved in policy-making. Some States have one approval agency, others have three or more. Usually the State health department is involved as well as the State department of environmental protection or a unit of water/pollution control. However, the agencies do not often have the same outlook on land treatment technology. Many States have lacked an organized policy statement or single source on what specific regulations or guidelines are concerning land application of wastewater. Many States that don't have an organized set of regulations or guidelines are now working on them, while approving land-treatment technologies on a case-by-case basis.

OVERLAND FLOW - OVERVIEW

A total of about 19 States mention overland flow technology specifically. Of these, at least half currently have their regulations or guidelines in draft form or under various stages of revision. Several States have very specific policies regarding overland flow technology with well-written regulations or guidelines. (See Figure 1,*)

There is a high correlation between States with existing or planned overland flow systems and those with regulations and guidelines. This is especially true in areas where the geographic and political climate are favorable to overland flow technology.

Geographically, the predominant soil in a State is the most important factor influencing State policy. Overland flow systems are designed to operate on soils with a very low permeability--this usually means soils with a high clay content. Extensive areas of clay soils exist in the Northern Central States, Mid-Atlantic States, and especially Southeastern United States. (See Figure 2.)

Moving West, one finds larger areas of sandy soils which are unsuitable for overland flow systems. Also, it becomes much drier in the Western States. The lack of water significantly influences State policy.

Two doctrines, the Riparian and Appropriations Doctrines, are used to resolve water rights' conflicts where there are competing interests for water. (See Figure 3.)

The Riparian Doctrine is used predominately in the Eastern and Mid-Western States where water is generally in abundant supply. The Riparian Rights Doctrine has little or no direct bearing on municipal land treatment systems in the Eastern United States where water is abundant. However, the Appropriations Doctrine has limited the practice of land application of wastewaters in some Western States.

Because of the geographic and political problems associated with overland flow technology, it is not often addressed in Western State policy.

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*All Figures appear at end of this paper.

STATE SUMMARY

1. Region I

At present, the States in Region I do not have regulations or guidelines addressing overland flow and, in general, very little mention is made in State policy of land treatment. High groundwater tables, lack of sufficient land, and long winters are frequently cited by State officials as the reason for the unpopularity of land treatment of wastewater. However, there is an operational overland flow system in Connecticut, and an experimental system in New Hampshire. Many officials seem eager to learn more about overland flow technology and compliment recently heightened interest by local communities in overland flow, as an alternative method of wastewater treatment.

2. Region II

In Region II, New Jersey has drafted guidelines which contain criteria for the design and operation of overland flow systems. According to the New Jersey Department of Environmental Protection, two systems are already operating in New Jersey. Although New York has no regulations or guidelines addressing overland flow, preferring instead to look at proposed sites on a case-by-case basis, the State Department of Environmental Conservation maintains a flexible posture. The department stipulates that overland flow systems will be required to meet the same discharge requirements as conventional wastewater treatment facilities in order to obtain a permit.

3. Region III

In Region III, Maryland is one of the two States with guidelines pertaining to overland flow; the State also has a few nonmunicipal systems operating. The guidelines specify maximum elevation of groundwater (4 feet below the surface during wet season) at treatment sites, as well as application rates, slope ranges (2 to 8 percent) and preapplication water quality requirements. Virginia is the other State that sets standards for overland flow systems; the regulations state that slopes should be less than 4 percent, a minimum of 2 feet of soil shall be present, and monitoring and disinfection are required prior to being discharged. Virginia currently has at least one municipal overland flow system in the design phase. (See Table 1. Note tables appear at the end of this paper.)

4. Region IV

In Region IV, three States, Mississippi, Florida, and North Carolina set design and operating criteria for overland flow. Mississippi and Florida have relatively complete and well-written guidelines. Florida guidelines are still in the draft stage. Mississippi devotes almost three pages to overland flow technology, covering preapplication treatment (chlorination, if needed), storage (30 to 60 days above that required for treatment), hydraulic loading rate (2.5 inches/week minimum for the yearly average), distribution system, application field characteristics (slope, soil permeability depth to groundwater), vegetative cover, drainage/

collection systems, post chlorination, buffer zone, public access and monitoring. It's interesting to note that, although detailed, a good deal of flexibility is built into the guidelines. For example, with respect to buffer zones, the guideline stated: "The size of this border is dependent upon application method, proximity to dwellings, roads, land use, etc. Although a width of the buffer is negotiable, a volume of 50 to 100 feet would seem to be adequate for most cases in which precautions have been taken to minimize spray drift and aerosols." Florida's regulations, although still not in final draft form, are similar in form and thoroughness of coverage of overland flow technology. North Carolina's proposed guidelines are less lengthy, but cover all the major criteria considered in land application. Although the other States in Region IV have predominately clay soils, they currently have no regulations or guidelines on overland flow systems. (See Table 2.)

5. Region V

In Region V, five of the six States have regulations or guidelines on overland flow (although Minnesota and Indiana have only draft guidelines). Wisconsin guidelines, written with the help of the State University, explain the treatment process and recommended design criteria. Wisconsin and Illinois are the only States in the region with operational overland flow systems although other States are considering overland flow. Illinois and Indiana guidelines, although less detailed than Wisconsin's, are clear and concise. Michigan guidelines are more general, but do specify that disinfection is not required for effluents applied by flooding or overland flow. Ohio, at present, has no regulations or guidelines on overland flow. The low permeability of much of the State's soil indicates a good potential for overland flow technology. (See Table 3.)

6. Region VI

In Region VI, Louisiana, Arkansas, and Texas all have guidelines, although Louisiana's are in draft form. The Arkansas State Department of Pollution Control and Ecology and the Department of Health have just recently completed a 53-page publication dealing exclusively with land application, with seven pages devoted to overland flow technology. It is probably the most comprehensive, easy-to-follow, and up-to-date set of guidelines covering overland flow systems. The guidelines contain diagrams and charts of application schedules, equations, and sample calculations for determining loading rates, a section devoted to Nitrogen balance, and a rationale for nitrogen removal with a discussion of management of nitrogen removal. In addition, there is an easy-to-understand section on phosphorous removal, accompanied with charts and a section on hydraulic loading, complete with graphs and equations for practical use. Texas design criteria are also well written and list specific guidelines and parameters of concern, although currently they are under revision. Texas has more operating land treatment facilities than any other State and includes an industrial overland flow system. Oklahoma does not have regulations or guidelines on overland flow, but is actively studying the technology to determine its performance, while looking at existing regulations and guidelines to use in determining their own standards.

Louisiana has drafted new guidelines on overland flow systems to update existing State guidelines. Part of the revisions include changing the previously suggested application rate from 2 inches/week to 4 inches/per week. This change is largely a result of the analysis of data from test facilities, mainly the Utica facility in neighboring Mississippi. (See Table 4.)

7. Region VII

In Region VII, Nebraska sets general standards for overland flow systems, while Iowa has a moderately detailed set of criteria. Missouri has no official publication, but uses guidelines developed by the University of Missouri Extension Department. (See Table 5.)

8. Region VIII

In Region VIII, only North Dakota has issued some form of standards for land treatment of effluent concerning overland flow systems. However, Utah has an operational overland flow system and Wyoming is now drafting guidelines with detailed consideration given to overland flow. Presumably, water rights' concerns are the biggest factor influencing decisions in this region.

9. Region IX

In Region IX, no States have regulations or guidelines on overland flow. However, California does have one operational overland flow system and has an active interest in the technology. California uses its own system for categorizing land treatment facilities (which doesn't include overland flow as a category), but State officials recognize overland flow as a desirable wastewater treatment option. Hawaii also has an overland flow system.

10. Region X

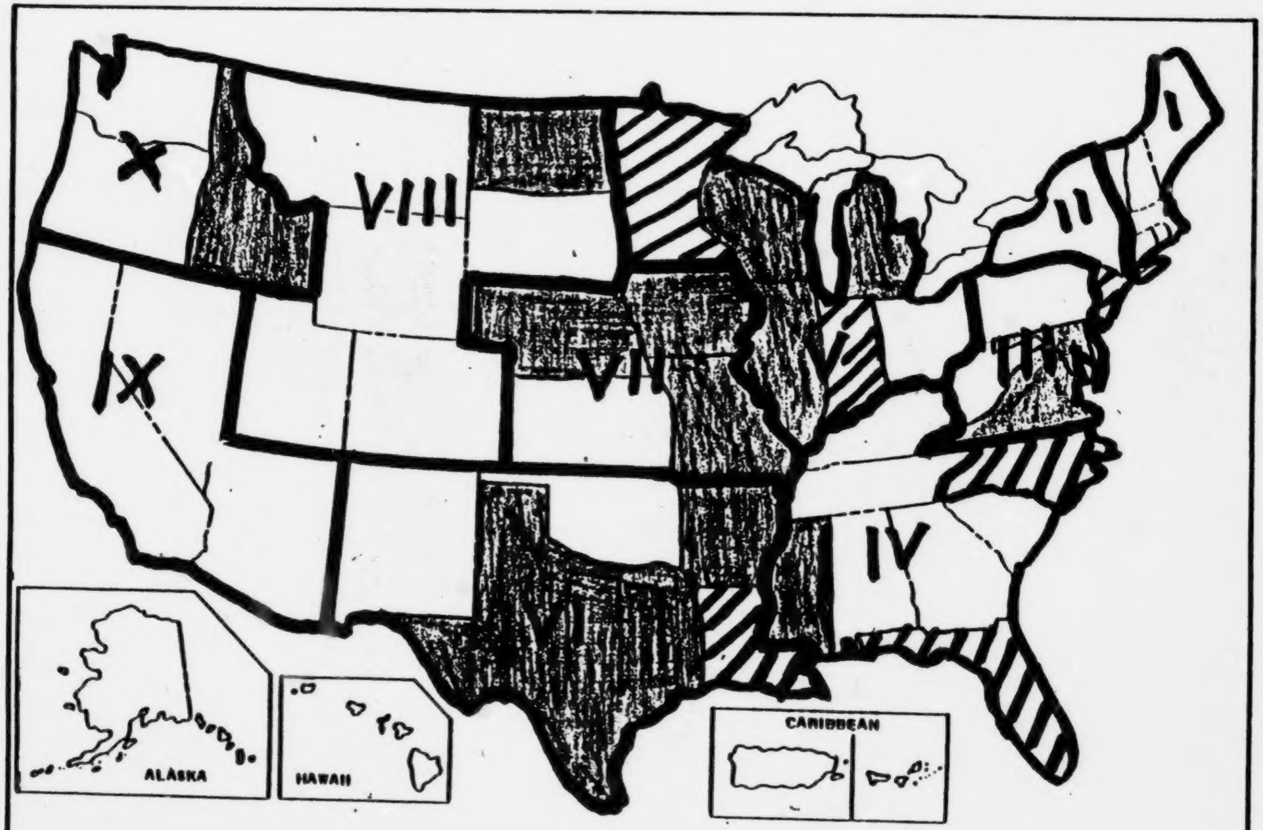
In Region X, Idaho expresses a strong interest in overland flow systems. The State has just issued a technical report that treats overland flow technology in depth. A slightly unique table is included which lists all the soil series identified in the State and the limitations associated with using a given soil for different land application systems. Also, a process design figure is included showing a step-by-step typical design procedure to be used in selecting hydraulic loading. Idaho, presently, has two overland flow systems with several more planned.

CONCLUSION

A general concern expressed by most States that have regulations or guidelines involves protecting ground and surface waters. Most of these States require that overland flow systems that discharge to a water course meet the same water quality requirements that a conventional wastewater treatment facility would have to meet.

One interesting observation evident from studying States' policies is that, in most cases, it is only within the last four or five years that States have formulated a written policy on overland flow technology and in those States overland flow is gaining acceptance as a practical, cost-effective, environmentally-sound alternative. Other States are looking at overland flow systems on a case-by-case basis. This is a smart approach for States to follow initially, until a larger data base is developed from first-hand experiences with overland flow systems within the State,

Consideration of overland flow systems as a cost-effective, environmentally-sound pollution control alternative is a positive State strategy to follow for the 1980's.

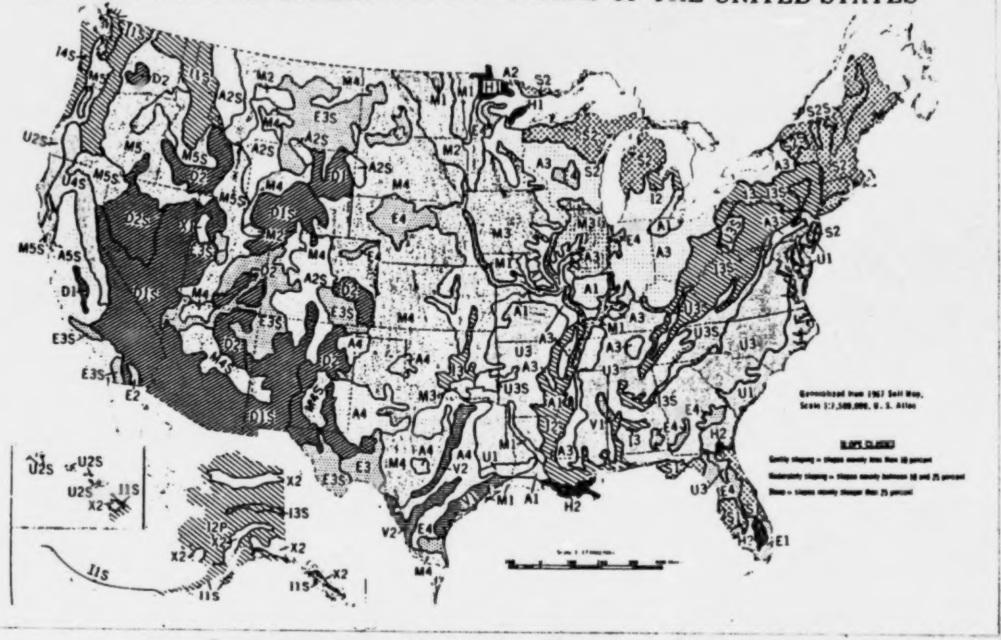


LEGEND:
▩ - Existing Overland Flow Guidelines
▨ - Draft Overland Flow Guidelines

Figure 1

SOIL CONSERVATION SERVICE

PATTERNS OF SOIL ORDERS AND SUBORDERS OF THE UNITED STATES


Generalized from 1967 Soil Map, Scale 1:7,500,000, U. S. Atlas
SLOPE CLASSES
Gently sloping – slopes mostly less than 10 percent
Moderately sloping – slopes mostly between 10 and 25 percent
Steep – slopes mostly steeper than 25 percent

Patterns of soil orders and suborders of the United States using the new comprehensive soil classification system.
(Map courtesy Soil Survey Division U.S. Soil Conservation Service.)

U. S. DEPARTMENT OF AGRICULTURE

LEGEND

Only the dominant orders and suborders are shown. Each delineation has many inclusions of other kinds of soil. General definitions for the orders and suborders follow. For complete definitions see Soil Survey Staff, Soil Classification, A Comprehensive System, 7th Approximation, Soil Conservation Service, U. S. Department of Agriculture, 1960 (for sale by U. S. Government Printing Office) and the March 1967 supplement (available from Soil Conservation Service, U. S. Department of Agriculture). Approximate equivalents in the modified 1938 soil classification system are indicated for each suborder.

ALFISOLS . . . Soils with gray to brown surface horizons, medium to high base supply, and subsurface horizons of clay accumulation; usually moist but may be dry during warm season

A1 AQUALFS (seasonally saturated with water) gently sloping; general crops if drained, pasture and woodland if undrained (Some Low-Humic Gley soils and Planosols)

A2 BORALFS (cool or cold) gently sloping; mostly woodland, pasture, and some small grain (Gray Wooded soils)

A2S BORALFS steep; mostly woodland

A3 UDALFS (temperate or warm, and moist) gently or moderately sloping; mostly farmed, corn, soybeans, small grain, and pasture (Gray-Brown Podzolic soils)

A4 USTALFS (warm and intermittently dry for long periods) gently or moderately sloping; range, small grain, and irrigated crops (Some Reddish Chestnut and Red-Yellow Podzolic soils)

A5S XERALFS (warm and continuously dry in summer for long periods, moist in winter) gently sloping to steep; mostly range, small grain, and irrigated crops (Noncalcic Brown soils)

ARIDISOLS . . . Soils with pedogenic horizons, low in organic matter, and dry more than 6 months of the year in all horizons

D1 ARGIDS (with horizons of clay accumulation) gently or moderately sloping; mostly range, some irrigated crops (Some Desert, Reddish Desert, Reddish-Brown, and Brown soils and associated Solonetz soils)

D1S ARGIDS gently sloping to steep

D2 ORTHIDS (without horizons of clay accumulation) gently or moderately sloping; mostly range and some irrigated crops (Some Desert, Reddish Desert, Sierozem, and Brown soils, and some Calcisols and Solonchak soils)

D2S ORTHIDS gently sloping to steep

ENTISOLS . . . Soils without pedogenic horizons

E1 AQUENTS (seasonally saturated with water) gently sloping; some grazing

E2 ORTHENTS (loamy or clayey textures) deep to hard rock; gently to moderately sloping; range or irrigated farming (Regosols)

E3 ORTHENTS shallow to hard rock; gently to moderately sloping; mostly range (Lithosols)

E3S ORTHENTS shallow to hard rock; steep; mostly range

E4 PSAMMENTS (sand or loamy sand textures) gently to moderately sloping; mostly range in dry climates, woodland or cropland in humid climates (Regosols)

HISTOSOLS . . . Organic soils

H1 FIBRISTS (fibrous or woody peats, largely undecomposed) mostly wooded or idle (Peats)

H2 SAPRISTS (decomposed mucks) truck crops if drained, idle if undrained (Mucks)

INCEPTISOLS . . . Soils that are usually moist, with pedogenic horizons of alteration of parent materials but not of accumulation

I1S ANDEPTS (with amorphous clay or vitric volcanic ash and pumice) gently sloping to steep; mostly woodland; in Hawaii mostly sugar cane, pineapple, and range (Ando soils, some Tundra soils)

I2 AQUEPTS (seasonally saturated with water) gently sloping; if drained, mostly row crops, corn, soybeans, and cotton; if undrained, mostly woodland or pasture (Some Low-Humic Gley soils and Alluvial soils)

I2P AQUEPTS (with continuous or sporadic permafrost) gently sloping to steep; woodland or idle (Tundra soils)

I3 OCHREPTS (with thin or light-colored surface horizons and little organic matter) gently to moderately sloping; mostly pasture, small grain, and hay (Sols Bruns Acides and some Alluvial soils)

I3S OCHREPTS gently sloping to steep; woodland, pasture, small grains

I4S UMBREPTS (with thick dark-colored surface horizons rich in organic matter) moderately sloping to steep; mostly woodland (Some Regosols)

MOLLISOLS . . . Soils with nearly black, organic-rich surface horizons and high base supply

M1 AQUOLLS (seasonally saturated with water) gently sloping; mostly drained and farmed (Humic Gley soils)

M2 BOROLLS (cool or cold) gently or moderately sloping, some steep slopes in Utah; mostly small grain in North Central States, range and woodland in Western States (Some Chernozems)

M3 UDOLLS (temperate or warm, and moist) gently or moderately sloping; mostly corn, soybeans, and small grains (Some Brunizems)

M4 USTOLLS (intermittently dry for long periods during summer) gently to moderately sloping; mostly wheat and range in western part, wheat and corn or sorghum in eastern part, some irrigated crops (Chestnut soils and some Chernozems and Brown soils)

M4S USTOLLS moderately sloping to steep; mostly range or woodland

M5 XEROLLS (continuously dry in summer for long periods, moist in winter) gently to moderately sloping; mostly wheat, range, and irrigated crops (Some Brunizems, Chestnut, and Brown soils)

M5S XEROLLS moderately sloping to steep; mostly range

SPODOSOLS . . . Soils with accumulations of amorphous materials in subsurface horizons

S1 AQUODS (seasonally saturated with water) gently sloping; mostly range or woodland; where drained in Florida, citrus and special crops (Ground-Water Podzols)

S2 ORTHODS (with subsurface accumulations of iron, aluminum, and organic matter) gently to moderately sloping; woodland, pasture, small grains, special crops (Podzols, Brown Podzolic soils)

S2S ORTHODS steep; mostly woodland

ULTISOLS . . . Soils that are usually moist with horizon of clay accumulation and a low base supply

U1 AQUULTS (seasonally saturated with water) gently sloping; woodland and pasture if undrained, feed and truck crops if drained (Some Low-Humic Gley soils)

U2S HUMULTS (with high or very high organic-matter content) moderately sloping to steep; woodland and pasture if steep, sugar cane and pineapple in Hawaii, truck and seed crops in Western States (Some Reddish-Brown Lateritic soils)

U3 UDULTS (with low organic-matter content; temperate or warm, and moist) gently to moderately sloping; woodland, pasture, feed crops, tobacco, and cotton (Red-Yellow Podzolic soils, some Reddish-Brown Lateritic soils)

U3S UDULTS moderately sloping to steep; woodland, pasture

U4S XERULTS (with low to moderate organic-matter content, continuously dry for long periods in summer) range and woodland (Some Reddish-Brown Lateritic soils)

VERTISOLS . . . Soils with high content of swelling clays and wide deep cracks at some season

V1 UDERTS (cracks open for only short periods, less than 3 months in a year) gently sloping; cotton, corn, pasture, and some rice (Some Grumusols)

V2 USTERTS (cracks open and close twice a year and remain open more than 3 months); general crops, range, and some irrigated crops (Some Grumusols)

AREAS with little soil . . .

X1 Salt flats

X2 Rockland, ice fields

NOMENCLATURE

The nomenclature is systematic. Names of soil orders end in *sol* (L. *solum*, soil), e. g., ALFISOL, and contain a formative element used as the final syllable in names of taxa in suborders, great groups, and sub-groups.

Names of suborders consist of two syllables, e. g., AQUALF. Formative elements in the legend for this map and their connotations are as follows:

and – Modified from Ando soils; soils from vitreous parent materials
aqu – L. aqua, water; soils that are wet for long periods
arg – Modified from L. argilla, clay; soils with a horizon of clay accumulation
bor – Gr. boreas, northern; cool
fibr – L. fibra, fiber; least decomposed
hum – L. humus, earth; presence of organic matter
ochr – Gr. base of ochros, pale; soils with little organic matter
orth – Gr. orthos, true; the common or typical
psamm – Gr. psammos, sand; sandy soils
sapr – Gr. sapros, rotten; most decomposed
ud – L. udus, humid; of humid climates
umbr – L. umbra, shade; dark colors reflecting much organic matter
ust – L. ustus, burnt; of dry climates with summer rains
xer – Gr. xeros, dry; of dry climates with winter rains

AUGUST 1967

Figure 2

Reproduced from best available copy.

DOMINANT WATER RIGHTS DOCTRINES AND AREAS OF WATER SURPLUS OR DEFICIENCY

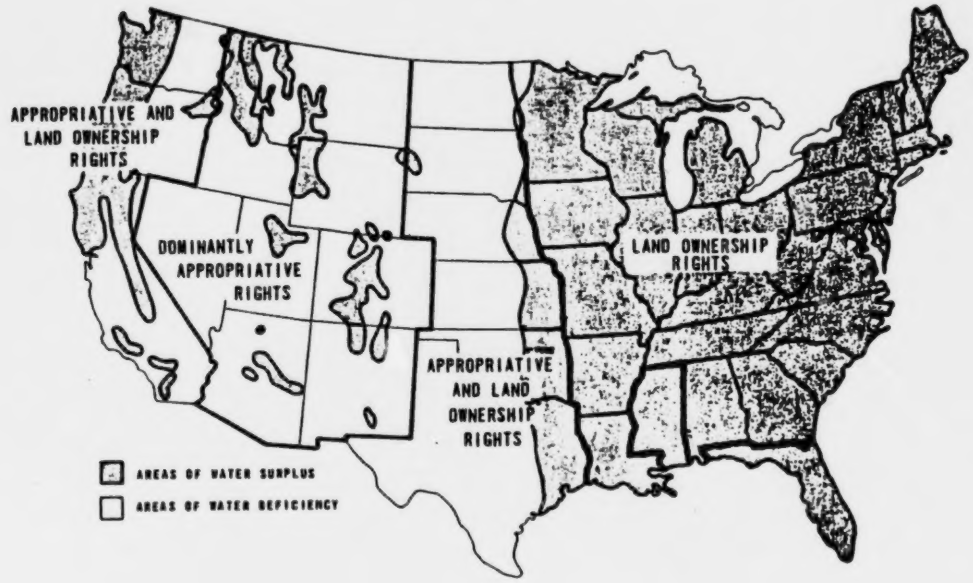

APPROPRIATIVE AND LAND OWNERSHIP RIGHTS
DOMINANTLY APPROPRIATIVE RIGHTS
LAND OWNERSHIP RIGHTS
APPROPRIATIVE AND LAND OWNERSHIP RIGHTS
AREAS OF WATER SURPLUS
AREAS OF WATER DEFICIENCY

Figure 3

Table 1

	REGION III						
	OVERLAND FLOW DESIGN CRITERIA						
STATES IN REGION III	Weather Restrictions	Buffer Zones	Monitoring	Runoff	Slope	Crop Cover	Storage
Maryland	0	X	X	X	X	X	X
Virginia	X	X	X	X	X	X	X
Pennsylvania							
West Virginia							
Delaware							

LEGEND:

X denotes the State has regulations or guidelines

0 denotes on a case-by-case basis

Table 2

STATES IN REGION IV	REGION IV						
OVERLAND FLOW DESIGN CRITERIA	Weather Restrictions	Buffer Zones	Monitoring	Runoff	Slope	Crop Cover	Storage
Mississippi	0	X	0	X	0	X	X
Florida	X	X	X	X	X	X	X
North Carolina	X	X	X	0	0	0	X
Tennessee							
Georgia							
South Carolina							
Tennessee							

LEGEND:

X denotes the State has regulations or guidelines

0 denotes on a case-by-case basis

Table 3

STATES IN REGION V	REGION V						
OVERLAND FLOW DESIGN CRITERIA	Weather Restrictions	Buffer Zones	Monitoring	Runoff	Slope	Crop Cover	Storage
Wisconsin	X	0	X	X	X	X	0
Illinois	X	0	X	X	X	0	X
Michigan	0	X	0	0	0	0	0
Minnesota	0	0	0	X	0	0	0
Indiana	X	0	X	X	X	0	X
Ohio							

LEGEND:

X denotes the state has regulations or guidelines

0 denotes on a case-by-case basis

Table 4

OVERLAND FLOW DESIGN CRITERIA	REGION VI						
STATES IN REGION VI	Weather Restrictions	Buffer Zones	Monitoring	Runoff	Slope	Crop Cover	Storage
Arkansas	X	X	X	X	X	X	X
Texas	0	X	X	X	X	X	X
Louisiana	X	0	0	X	0	0	X
Oklahoma							
New Mexico							

LEGEND:

X denotes the State has regulations or guidelines

0 denotes on a case-by-case basis

Table 5

OVERLAND FLOW DESIGN CRITERIA	REGION VII						
STATES IN REGION VII	Weather Restrictions	Buffer Zones	Monitoring	Runoff	Slope	Crop Cover	Storage
Iowa	X	X	0	X	X	X	0
Nebraska	X	0	0	X	0	0	0
Missouri	X	0	0	0	X	X	0
Kansas							

LEGEND:

X denotes the state has regulations or guidelines

0 denotes on a case-by-case basis

PB82-194259

Panel Discussion with State Agency Representatives

(Questions to follow last presentation)

Harry Pruett, P.E., Assistant Director
Permits Division, Texas Department of Water Resources
Austin, TX

The first thing I must mention is that we currently have no systems treating domestic sewage in Texas that utilize the overland flow technique. I think most here are familiar with the Campbell Soup system in Paris, Texas which deals with industrial waste and has been quite successful. It has been written about extensively, and we are quite satisfied with its performance. Although we have no constructed or operating municipal wastewater overland flow systems, overland flow criteria have been a part of our design guidance since the last revision of design criteria, which occurred in 1976. We are also in the draft stage on our entire design criteria, and I have brought with me 20 copies of our draft criteria concerning overland flow, for those who would like to take a look. I am here to learn what I can by testing these draft criteria for their validity as part of our overall consideration of amending our design criteria.

I noticed that we were noted as having "buffer zone" on regulation. That might be an error. I am not familiar with what has been referred to as the "buffer zone criteria." However, we are going to consider the general question of buffer zone in amending these criteria, and it may well be a controversial point. The kind of buffer zone strategy we would have, with regard to overland flow systems, would be identical to what we would consider appropriate for any other kind of treatment plant. In other words, we consider it a process comparable to most waste treatment systems that we are familiar with; it would be neither more stringent nor less stringent (in terms of buffer zone requirements).

Aside from design criteria (obviously we have to deal with those) we are concerned with a policy that constitutes direct discharge. Overland flow is absolutely not covered in our Chapter 18 of the Rules, which deals with effluent sets. Nevertheless, we have flexibility to deal with systems on a case-by-case basis in terms of permitting practice.

Therefore, whether our effluent policy needs to be modified near term is questionable. Obviously, we would like to see a few systems continue. We would like to be able to measure their performance before finalizing effluent performance criteria, as might be appropriate. Yet some of the questions that I bring to this particular meeting concern the permit process, one of which is a Federal question, the other a State question. The Federal question relates to our secondary treatment information, 30/30. Obviously, properly designed and loaded overland flow systems should be able to do better than the 30/30.

But our real question has to do with TSS. Is TSS an appropriate control parameter to be used in regulating overland flow systems? What sort of designs might we use if we insist on it?

The one modification that may possibly have occurred historically has been oxidation pond TSS. That modification took a great deal of time and data to secure.

We would be inclined to adopt the more stringent BOD limitation, and waive TSS. However, in terms of preparing the National Pollution Discharge Elimination System (NPDES) permits, it is the final desire of our Regional Office to include TSS parameters, though we would still have reservations about the use of TSS to regulate such overland flow systems.

The State question deals with the chemical disinfection of our systems throughout the years. We are inclined to think that, given the normal storage encountered prior to application and the action of the system itself, chemical disinfection probably is not required. However, we will look at it on a case-by-case basis, and I suspect that we will not be requiring chlorination for such systems. Therefore, in terms of the permit process, you are working here with a very irregular set of parameters.

I would like to address the subject of attitude. The attitude of the State is clearly favorable, but only if the site-specific factors support its selection over other treatment alternatives. For the State to act favorably in the consideration of both land and permit procedures, we insist on evidence that the location is correct; that the soil is suitable; that the design is appropriate; and that the project can be adequately reviewed and approved for construction. I have with me the copy of our draft criteria which will be published with our other proposed criteria, and we are looking for constructive criticism or comments on those criteria.

PB82-194267

Jack Witherow
Robert S. Kerr Environmental Research Laboratory
U.S. Environmental Protection Agency, Ada, OK

I am representing the State of Louisiana at their request. I think that Louisiana is more than positive about overland treatment. They are actually encouraging it. The State and EPA recently sponsored a workshop, and as part of that workshop a preliminary policy was developed--a ten-page document. This was distributed and discussed at the workshop, and the State asked for review comments from the consultants who attended this design workshop. EPA's Land Treatment Task Force, and Headquarters' Staff also reviewed these guidelines. Many of the statements are suggestions rather than requirements. This draft policy addresses unique items in the State of Louisiana. I recommend that you obtain a copy for your information.

The policy covers all three types of land treatment that will all be in Louisiana shortly. Today I will address only those items which deal with overland flow.

The first thing that all consultants should be interested in is that the guidelines prescribe certain information which should be in the facility plan. Most of these items are obvious, but having looked at a number of facility plans, I can assure you they are often omitted; such items as topography maps, soil maps, hydrology reports, meteorology, and crops.

Each facility planner will be asked to include information on these items, and the guidelines go into detail about how much information. Next they suggest areas where overland flow and the other types of systems will best fit in terms of soil permeability, depths of ground water, and soil texture. The guidelines do not say that these are requirements. In essence, they give you some guidance on which system might best fit the available sites.

One of the most unique things about these guidelines is their definition of primary treatment. The guidelines ask for primary treatment prior to land application in all cases, and for particular types of land use or crop use, more than primary treatment is required. The definition of the primary treatment suitable for land application facilities is a treatment that will produce an effluent of 100 mg per liter of BOD or less. There are several systems that are described as suitable. One is an oxidation pond with loadings up to 62 pounds of BOD per acre per day. Another is a 24-hour aerated lagoon. The guidelines also list existing facilities that are capable of meeting that requirement.

I looked up the possibilities of using a primary clarifier. In parts of Louisiana where they have infiltration and dilute waste, the effluent can be 100 mg/l of BOD from primary sedimentation. Since secondary treatment is not required for overland flow systems, I won't describe that part of the guidelines.

I will read the portion of the statement on storage requirements: "A 10-day storage will be considered within the range for overland flow facilities." You might wonder how 10 days' storage was selected for Louisiana when storage requirements are commonly based on cold climates. In Louisiana, the climate is such that this storage is based on operational needs.

In other words, the range of 10 days was selected knowing that it might take 10 days for a small operator to fix the pump. That accounts for the slightly different concept of storage from what you have been familiar with in colder climates.

Mr. Dyer mentioned that one of the States recently increased its application rates for overland flow. Louisiana is one that has done so. The original guidelines, which came out about three years ago, recommended application of 2 inches a week. Many felt that that was making the system unnecessarily costly. Now the statement reads, "Application rates should not exceed 4 inches per week." Higher application rates may be allowed if better than primary treatment is achieved, or justified by other means.

The guidelines also limit length of slope to 100 to 200 feet; degree of slope to 2 to 8 percent; and instantaneous application rate to no more than 0.1 inch per hour.

There are other items in the guidelines about monitoring disinfection. The State has indicated that overland flow discharge to shellfish waters would most likely be required to have disinfection.

Again, I would encourage all those who are going to work with the State of Louisiana to review the document. The State is actively looking for comments and suggestions.

PB82-194275

Mr. Martin Roy
Arkansas Department of Pollution-Control and Ecology
Little Rock, AR

I will give you a little background on how the State of Arkansas developed its land application guidelines, which include overland flow. This may benefit those States that have not gone through that procedure yet, or may be getting into it soon.

In Arkansas, we initially took the EPA design and obtained information on land application from each State whose border touched Arkansas. Then we contracted specific individuals in those States who had training in land application, and asked them to write a section of our guidelines. The regulatory agencies set up the basic outlines for the items that we wanted to cover, and then we assigned sections to individuals. Some of the individuals involved were regulatory people; however, the majority were consulting engineers. We did this for two reasons. First, we did not have the manpower nor the time as a regulatory agency to do it entirely ourselves. Second, we wanted to have an input from the engineering community into our guidelines.

After the various individuals had accepted the responsibility and written their sections, we compiled them into what is known as the draft guidelines. The draft guidelines were then sent to various reviewers, including soil specialists, educational specialists, specialists in agricultural practices, other consulting engineers who have worked with land application, and a number of other people in this field. People within the regulatory agencies were also sent copies and asked to comment on the guidelines.

These comments were then reviewed on a case-by-case basis. We looked at each comment specifically. Some of them were good comments; some of them not quite appropriate to the situation; and some of them could be used if modified.

Based on the comments, we compiled our advance guidelines, and this is where we are right now. This is an advance copy of the "Arkansas Land Application Guidelines for Domestic Wastewaters." We sent copies out again to much the same people that made the initial review and asked them if they wanted to comment further on the advance guidelines. Some comments were received, and again we went through the evaluation procedure.

This is where we are now--in the process of rewriting the advance copy. When that has been corrected, it will be submitted to the various commissions and public health boards for their approval. It will then be promoted as the Arkansas Guidelines.

I would emphasize that they are being submitted as guidelines, not regulations. However, until we reach the final stage, we have told consulting engineers in the State to use for their guidance the latest version or edition that we have put out.

Right now, we have one project in Arkansas that is in operation using overland flow technology. We have one project that is currently being constructed. We have three projects that are in the planning stage.

All of these projects involve towns with a population of fewer than 400 people. I think what we will see in our State is that the rural communities will be the ones to accept the overland flow techniques primarily for two reasons. One, the rural community is acquainted with and has a feel for growing crops etc., so they may be more inclined to accept this type of treatment technology. Another very strong point that we have found is that most of the small communities have to borrow money from the Farmers Home Administration (FHA) as well as obtain EPA money, in order to construct these particular projects. Thus, by being able to realize some income from the paid production of their overland flow system, they are able to borrow more money from the FHA because it would be a revenue-producing system. This is one factor.

The engineers in Arkansas are becoming increasingly comfortable with overland flow systems. I feel that as we get more of them in the State and make progress with this technology, we will continue to see engineers working with these particular types of systems.

Initially, we had a strong inertia to overcome because the consulting engineers were encountering a new technology. They just did not feel comfortable with it, because they were dealing with many new and different disciplines. But as we go along, we get more experience and will likely see more of the systems in the State.

PB82-194283

Stephan Belanger
Mississippi Bureau of Pollution Control
Jackson, MS

Presently, in Mississippi, we have two operating overland flow systems. One is very small, 43,000 gallons a day, design flow. The other one is currently operating at about 0.6 MGD, and is in the process of upgrading to 0.8 MGD. We have planned a total of 13 land treatment systems, of which 9 are overland flow. These are in various stages of completion. All have at least an approved 201 Plan, except one where the Plan has not been approved, due to a restriction on the land availability. The planned facilities range from 50,000 gallons a day to 3.0 MGD. The total land being used in the larger one is approximately 600 acres.

Mississippi held a seminar much like this one in March, 1979. Several people that are speaking here also spoke at that seminar and brought forth valuable information to the consultants in the State, as well as to a number of town representatives who were also there.

Subsequent to that seminar, we developed draft guidelines. We are using draft guidelines--the reason for this being that the concept of land treatment, all three phases, is changing so rapidly. As new systems are designed, built, and put into operation, we will need to revise and revise again.

We look upon our guidelines as guidance, not requirements. We, in Mississippi, do not feel that we should overly restrict the work of the consultant engineer. Our guidance system is intended to direct the engineer in the 201 planning phase to ensure that land treatment has been given adequate consideration.

Dick Thomas mentioned that one State has succeeded in obtaining a deviation from the regulations to require the consultant to look at overland flow and the slow-rate system, instead of only at the rapid- the slow-rate systems.

In Mississippi we are also proceeding to obtain this deviation. We have preliminary concurrence from EPA and now need to submit justification in segments related to the three general methods and indicate what will be required during the planning phase.

Going over our guidelines, I will point out areas where we might agree or disagree with some of the other States, and possibly also with the Federal guidelines.

Preapplication treatment: In Mississippi we do not subscribe to the concept of going on the land with raw sewage at this time. Generally we ask the consultant to give consideration to an oxidation pond with a loading of approximately 50 pounds per acre per day. This value is based on an odor possibility. If the system facility for the community is already a lagoon, or if they have no treatment at all, then we would ask the consultant to give consideration not only to the facultative lagoon, but also the short detention time aerated lagoon.

Our approach to the storage is also possibly different. We feel that in this facultative pond, which is loaded at 50 pounds per acre per day, we would get somewhere around 30 to 50 days storage. We also will ask consultants in the future to consider the possibility of going to an off-line storage for more than what is required for pretreatment to keep down the algae production before going onto the slopes.

Preapplication chlorination: We look at this on a case-by-case basis and recognize that it would not generally be required if the application is a low head system or has been designed to minimize production of aerosols. Our State Board of Health, located in Jackson, has concurred with this on two projects to date.

The hydraulic loading rate: We have set up a minimum to be considered in 201 Planning. We plan on 2.5 inches per week for a yearly average over the entire site. In some cases, the engineers have taken it upon themselves to go above this figure. The plans that I have seen and reviewed have been for 3.5 inches per week. This is one area where we might want to revise the guidelines.

Distribution systems: We very much encourage the low-energy systems--low head, like the gooseneck fixed-fan nozzles, gated pipes, etc. The largest system to date which has virtually completed design is using impact-pressure nozzles, which have a low trajectory angle. We feel the production of aerosols will be minimized with these.

Application field characteristics: Slopes of 100 to 150 foot (2 to 8 percent) of terrace length are recommended. Soil permeability comes into play in overland flow-type systems. The State Board of Health has agreed without determination that the monitoring of the underlying groundwater would not be required if sufficient documentation is provided to indicate that the soil is extremely tight, which is generally the experience in overland flow. We work in conjunction with the Board of Health on this matter.

Postchlorination: At the present time, we are not requiring postchlorination on every facility. We require stream standards to be maintained, which are 2,000/4,000 for fecal coliform. In our opinion and that of the EPA Region IV's representative, using the preapplication treatment of the lagoon, plus the removal obtained on the slopes, this figure can be met. So, we are going to consider not using postchlorination at all until it has been established that we do need it.

Buffer zones: This is considered on a case-by-case basis. We recommend between 50 to 100 feet, depending upon proximity to houses, etc.

Monitoring of the ground water: I mentioned earlier that on overland flow slope systems we would generally expect that this will not be required due to the soil impermeability.

Discharge to the surface stream: I commented earlier on overland NPDES permits. In that document we require all the necessary monitoring for BOD, suspended solids, fecal coliform, etc.

I only brought one copy of my guides. If anyone would like a copy of this, please contact our office.

PB82-194291

Charles D. Newton, Chief
Water Facilities Engineering Service,
Oklahoma State Department of Health, Oklahoma City, OK

I did not bring any copies of my guidance. As you noticed on the map, Oklahoma is not shown as having any.

In 1965, the State Department of Health, or the State Board of Health, adopted a policy statement aimed at upgrading the water pollution control program in the State of Oklahoma. That statement gave us three different directions in which to move.

One, it adopted a minimum sector treatment for municipal wastes. At the same time it encouraged joint municipal and industrial treatment systems for compatible waste. It also requested our State Department of Health to support research in advanced waste treatment methods and in the reuse of water for all purposes, with particular emphasis on the value of wastewater for irrigation.

We started in 1965, attempting to implement a program in the reuse of wastewater realizing the nutrient values. We were not functioning as a "health department" and possibly did not recognize all the hazards. We didn't consider the hazards to be much worse than pouring wastewater into a stream.

We encouraged consultants to come up with land application projects. We were trying to develop our concept of keeping the wastewater out of the stream and keeping the nutrients on the land where they belonged. Overland flow was not then in the picture.

Then we attempted to implement a program. We attended some research conferences and encouraged our two major universities to become involved in this area. After two or three years, we decided they weren't really interested in this work, and also EPA came out with a proposal. At that time we decided to implement a research project ourselves--and that became the Pauls Valley Project.

The Health Department apparently does not enter into this work, because we had a lot of headaches. However, I think we may have promoted the concept of wastewater land application reuse, and if we did, it was all worthwhile.

We did take the EPA guidelines on land application of wastewater. We had our Soil Conservation Service agricultural experts out of Stillwater, and our consulting engineers review the EPA document and some drafts that we had made of it, trying to adapt it to Oklahoma conditions. And we have a book entitled "Land Application Guidelines for Oklahoma," which you can obtain by writing to the Oklahoma State Department of Health. The book largely pertains to buffer zone and items of this nature--probably very similar to what is in the EPA publication, but the two may vary.

With regards to our policy on overland flow, we have agreed to consider several more projects in Oklahoma. We are not going to saddle the consultants with a lot of rigid guidelines. We want a consultant to apply what he has learned from EPA and give us a good project. We want everybody to recognize that this is innovative. At this time we don't consider it a proven technology; there is risk involved. When we at the Health Department approve it and something goes wrong, the consulting engineer or the city will not be threatened with lawsuits, EPA enforcement, or similar problems. We want a way by which we can get that 100 percent money to return to the project and correct whatever went wrong.

Question (by Mr. Tom Ellison, Texas Department of Water Resources, Austin, TX): Are the toxic materials going to be a problem with this type of system? Will some of the later speakers touch on some work done with toxic substances in wastewater? Have you looked at that in any of the State Guidelines?

Response (by Mr. Dyer): Toxics are an area we have not specifically looked at with regard to land treatment in overland flow. This is mainly due to another aspect of the Clean Water Act which is concerned with the development of the industrial pretreatment programs that will be placed on all municipalities on a case-by-case basis, specifically on those with systems greater than 5.0 MGD which receive industrial waste. Publicly owned treatment plants with less than 5.0 MGD, which have significant industrial wastewater contributions in their system, will have permit problems. It is an encompassing program, and the pretreatment program really should eliminate a large number of doubts about our land treatment systems, because of the removal of toxic pollutants from industrial sources. It will take several years for all of the standards to be implemented, but there is an ongoing program across the country now to develop pretreatment programs, to enforce categorical standards, and to control prohibitive discharges into their systems. So, really, those two coupled together should also enhance the applications of land treatment sytems. Generally speaking, control of toxics will take care of itself.

Question (by Dr. Harlin): You said that we were in the midst of developing this pretreatment process, and you also said that the program will become effective several years down the road, as far as the States adopting it. Can the five panelists say something about toxics now? Evidently toxics could be with us for a few years before the pretreatment standards really come into effect. What is the concern in the interim?

Response (by Mr. Dyer): This is a long story about pretreatment. From what EPA is finding in the categorical development of standards in specific industrial classes, there is not as much of a problem with toxics--organics--as they originally conceived in municipal systems. The standards that will come out are being delayed, largely in order to obtain factual data on which toxic substances should be controlled.

The biggest problem now being addressed is the heavy metals which drop out in sludge. It would be a very specific application where toxics could be a big problem in overland treatment systems. That is my viewpoint, from having been involved in pretreatment programs. Towns are developing programs now, but what is still some time away are the Federal standards that would be specific to categorical industries.

Question (by Mr. Dick Corneille, Metcalf and Eddy Engineers, San Bernadino, CA): It seems to me that some of the pretreatment requirements of the States may not be compatible with the EPA guidelines that have been published in program department memoranda for pretreatment as a treatment process. I am wondering if in the review process the State standards will be upheld, or will the EPA guidance, in the review of concept approval process? Also, how does EPA view some of these standards that seem to be a little strict?

Response (by Mr. Roy): When we wrote our guidelines, we had in mind specifically that we were not writing the guidelines to meet EPA grant requirements. We were writing the guidelines to meet our requirements.

We had the EPA grant requirements in the back of our minds as we did this. And in some cases, we compromised to the extent that they would be acceptable to the EPA, specifically Region VI, so that if a particular city wanted to get a grant of EPA money and use overland flow, they could do that. But in many cases, I think, we are much more stringent than the EPA requirements.

Additional Comments (by Mr. Thomas): I'll make a couple of clarifications. The EPA regulations do not require any specific preapplication treatment. The guidance for levels of preapplication treatment are issued in program requirements memoranda.

The guidelines for overland flow indicate a minimum of comminution or screening. Research results support this as a preapplication level for land treatment via overland flow.

We are working with the States in a positive mode to find the best way to operate in their climatic conditions.

Additional Comments (by Mr. Pruett): I would mention that we are looking for primary clarification, although it would be acceptable if a consultant engineer recommended use of oxidation ponds or other similar alternatives.

Additional Comments (by Mr. Witherow): Speaking as a member of the Task Force now, and not as a representative of the State of Louisiana, we have been involved with some of these different standards. In some cases they have been very easily resolved; in others they are not so easily resolved. Then you follow Mr. Newton's suggestion and have a conference between the State and EPA office to find out what is acceptable to both parties.

Question (by Dr. Robert Smith, University of California, Davis, CA): Have any of the States addressed the question of internal discharge quality requirements of an overland flow system associated with precipitation periods? Was this addressed specifically in each State's discharge standards?

Response (by Mr. Belanger): Yes, the State of Mississippi has addressed this problem. We have gone through the appropriate issues and procedures on the largest planned system in Mississippi, the Cleveland, Mississippi, system, 3.0 MGD a day; the pounds per day restriction will not be in effect during rainfall conditions.

The operators of the system are required in the permit to monitor and maintain records on specific precipitation--in inches and duration, etc.--so that we can go back and correlate that to any of the discharge. They will be monitoring the quantity of discharge during all of the situations, but they will have to meet the milligrams per liter both during rainfall and nonrainfall periods.

Additional Comments (by Mr. Pruett): As I indicated earlier, the State of Texas would be inclined to waive Total Suspended Solids (TSS) and chlorine residual requirements for overland flow discharges in certain cases.

PB82-194309

Developmental Research for Overland Flow Technology

Bert E. Bledsoe, Research Chemist
Robert S. Kerr Environmental Research Laboratory
U.S. Environmental Protection Agency

INTRODUCTION

Overland flow is the application of wastewater to a gently sloping terrace where the various physical, biological, and chemical processes renovate the wastewater as it flows down the treatment plot to the toe of the slope where it is collected by a berm or ditch for surface discharge.

It is especially suited for use on impermeable soils and falls intermediate between the infiltration-percolation approach and the crop irrigation approach in land area requirements. It is the least developed of these three soil treatment systems. The development of overland flow for domestic wastewaters originated from experiences with treatment and disposal of food processing water (1) and the land treatment systems at Werribee for the treatment of wastewater from the City of Melbourne, Australia (2). A twelve-month intensive study (3) of an overland flow treatment system for a cannery was conducted to evaluate the treatment efficiency on organic constituents and the nutrient compounds of nitrogen and phosphorus. The data from this study indicated that overland flow systems had the potential for achieving, with domestic wastewater, a high level of waste treatment and should be developed as a viable alternative for domestic wastewater treatment technology. Thus a program to develop the system for municipal wastewater treatment was initiated in 1970 at the Robert S. Kerr Environmental Research Laboratory.

FEASIBILITY STUDIES

The principal objectives of the initial study (4) were to evaluate the practicality of year-round treatment of raw wastewater in a moderate semi-humid climate, determine the allowable and optimum hydraulic loading rates, and develop sufficient design data to implement a full-scale system under comparable climatic conditions.

Raw domestic wastewater was obtained from the city sewer main, skimmed and comminuted to a fine particle size before being applied to overland flow treatment plots. The wastewater was distributed over the upper one-third of the plot by a single arm rotating boom, which had a fixed fan nozzle at the tip. Variance in the diameter of orifice of the nozzle allowed the different average aerial loadings. The treatment plots were 11 meters by 36 meters with a uniform slope of 2 to 4 percent.

Raw wastewater was applied for 18 months to the three treatment plots each receiving, respectively, 7.4, 8.6, and 9.8 cm per week. The study was divided into approximately three six-month study periods. The first being a system aging or acclimation period, and the remaining two periods being a winter and summer operation. The loading rates were seasonally adjusted so that a three-month duration winter rate was 85 percent of the average rate and the summer was 115 percent of average rate.

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Table 1 shows the quality of the raw comminuted wastewater (25 samples) which was applied to the treatment plots. Table 2 is the mean monthly concentration in runoff from all plots during system aging. The major stabilization period took from two to four months. Tables 3 and 4 are mean concentrations of selected parameters of runoff from the treatment plots for winter and summer operation.

TABLE 1. CHEMICAL CHARACTERISTICS OF RAW WASTEWATER FOR 18-MONTH STUDY PERIOD

	Concentration, mg/l		
Parameter	Mean	Maximum	Minimum
TSS	160	420	52
BOD	150	273	84
COD	314	620	130
TOC	89	198	21
TN	23.6	36.8	10.7
TKN	22.8	36.8	8.3
NH_3-N	17.0	29.0	6.9
NO_3-N	0.8	-	-
TP	10.0	15.0	4.8

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TABLE 2. TREATMENT EFFICIENCY IMPROVEMENT DURING SYSTEM AGING IN 1971

	Mean monthly concentration in runoff for all rates, mg/l				
Parameter	March	April	May	June	July
TSS	172	71	42	21	25
BOD	102	44	41	29	23
COD	158	148	104	71	95
TOC	56	55	36	31	42
TN	17.8	11.6	5.1	5.0	6.7
TKN	16.7	11.5	5.1	4.3	5.2
NH_3-N	12.9	4.2	1.8	1.6	1.4
TP	5.9	3.9	2.4	2.4	2.3

The results (4) of the eighteen-month study showed that the overland flow process is capable of achieving advanced waste treatment of raw comminuted wastewater when designed as a single-pass treatment process with no production of sludge. The effluent from this system contained less than 10 mg/l of total suspended solids (TSS) and biochemical oxygen demand (BOD).

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Total nitrogen (TN) ranged from 2 to 10 mg/l with concentration greater than 5 mg/l limited to a brief period of 2 to 3 months in the winter season largely as nitrate. Total phosphorus (TP) will be about 5 mg/l unless the system is designed especially for phosphorus removal.

TABLE 3. CHEMICAL QUALITY OF PLOT RUNOFF FOR WINTER OPERATION FROM NOVEMBER 1971 THROUGH APRIL 1972

	Mean concentration, mg/l		
Parameter	7.4 cm/wk plot	8.6 cm/wk plot	9.8 cm/wk plot
TSS	12	8	9
BOD	12	11	8
COD	53	48	46
TOC	22	14	15
TN	5.4	7.2	6.8
TKN	2.4	3.6	2.9
NH_3-N	0.5	2.0	1.3
NO_3-N	2.8	3.4	3.7
TP	4.4	5.4	5.1

TABLE 4. CHEMICAL QUALITY OF PLOT RUNOFF FOR SUMMER OPERATION FROM MAY 1972 THROUGH SEPTEMBER 1972

	Mean concentration, mg/l		
Parameter	7.4 cm/wk plot	8.6 cm/wk plot	9.8 cm/wk plot
TSS	8	6	8
BOD	11	7	8
COD	73	59	58
TOC	23	18	19
TN	2.6	2.2	2.2
TKN	1.8	1.7	1.7
NH_3-N	1.0	0.7	0.6
NO_3-N	0.4	0.5	0.4
TP	4.0	4.3	4.3

PHOSPHORUS REMOVAL STUDIES

The relatively low percentage of phosphorus removal experienced during the feasibility studies was the basis for this continuation study (5) for enhanced phosphorus removal. The principal factors to be evaluated in this study were continuing performance at the high loading of 10 cm per week and enhancement of phosphorus removal.

The original three plots used during the previous pilot-scale study were used for the enhanced phosphorus removal study. The three plots were receiving raw wastewater (skimmed and comminuted) at an average aerial loading of 10 cm per week. Table 1 shows the quality of the raw wastewater being applied to the three plots. One plot received only raw wastewater which was the control, while the two remaining plots received raw wastewater that had chemical additions of aluminum sulfate. The aluminum sulfate was injected into the raw wastewater lines several feet beyond the field pump header. The wastewater concentration of aluminum was raised to 14 mg/l and 20 mg/l, before application to the two experimental plots.

Considerable difficulty was encountered with the system for adding aluminum as a concentrated aluminum sulfate solution using a metering pump. The concentration of aluminum at the distribution boom nozzle varied greatly as shown in Table 5. Data for both plots receiving aluminum sulfate exhibited a quick response with the phosphorus concentration in the runoff dropping below 2.0 mg/l within 2 months as shown in Figure 1.* The phosphorus concentration in the plot runoff remained below this value for the remainder of the study, except for an increase during the last three months. This sharp increase was associated with a decrease in aluminum concentration at the distribution boom nozzle. The injection lines for the aluminum sulfate were partially clogged and the proper amount of chemical was not being added to the wastewater. During the period of low phosphorus in the runoff, the average concentration of aluminum was 25 mg/l with a range from 11 to 27 mg/l. During the last three months the aluminum concentration averaged 9 mg/l with a range of 7 to 11 mg/l.

TABLE 5. SPECIFIC DATA FOR THE PHOSPHORUS REMOVAL STUDY COVERING JUNE 1973 THROUGH FEBRUARY 1974

	Aluminum Added mg/l		Plot Runoff Concentrations from day 770 thru 1100 in mg/l			
			Aluminum		Phosphorus	
	Mean	Range	Mean	Range	Mean	Range
Control plot	0	--	.15	.07-.16	3.4	1.9-6.0
Low Al plot	14	2-27	.22	.06-.30	1.5	0.3-3.9
High Al plot	20	<5-40	.34	.10-.82	0.9	0.5-1.4

PRETREATMENT STUDY

This study (6) evaluated the effects of preapplication treatment of wastewater before being applied to an overland flow treatment system. The treatment plot effluent was evaluated against degree of preapplication treatment and also the hydraulic loading of the wastewater. Primary and secondary effluents were obtained from the municipal sewage treatment system. The secondary was from the final settling basin of a trickling filter. This should not be confused with lagoon effluent which is high in suspended solids and is algae laden.

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*Figures 1 to 8 appear at the end of paper.

The preapplication treated wastewater was applied at two different hydraulic loadings. The two primary wastewater plots received 15 and 20 cm per week, while the secondary wastewater plots were receiving 25 and 40 cm per week. The wastewater was applied six days a week for 12 hours a day during summer operation. This was generally from mid April to the last of November. The application cycle was reduced approximately 30 percent by applying 5 days a week for 10 hours per day for winter operation.

The applicators were converted from a rotating single arm boom to a rotating double boom with a spray nozzle at each end. This solved the problem of the strong winds causing the boom to apply its wastewater in only one section of the plot. Wastewater was applied for the first year using this type of applicators. After the first year's operation, the applicators were changed to fixed risers with the same type spray nozzles that had been on the rotating booms. The reasons for this change were problems of maintaining the boom swivels, and the increased hydraulic loading was washing away the soil under the spray pattern of the booms leaving only gravel and no vegetative growth.

Table 6 is a summary of the mean concentrations of the raw, primary, and secondary wastewaters for the preapplication treatment studies.

TABLE 6. MEAN COMPOSITION OF WASTEWATER FOR PREAPPLICATION TREATMENT STUDY

	Concentration, mg/l		
	Raw	Primary	Secondary
TSS	185	56	12
BOD	132	70	18
COD	328	120	55
TOC	87	35	16
TN	34	19	16
TKN	34	18	8
NH_3-N	23	14	6
NO_3-N	<1	1	8
TP	8	7	7

Figures 2a thru 2f are the cumulative relative frequency distributions of the effluent concentrations from the overland flow plots with varying degrees of preapplication treatment. Figure 2a shows that the increasing level of preapplication treatment decreased the TSS concentration in the effluent. This figure indicates that to meet a standard of less than 10 mg/l TSS for 90 percent of the time and hydraulic loading of 20 to 25 cm per week, secondary treatment is needed, in this case a trickling filter. Total organic carbon (TOC) in Figure 2b shows the same relationship as TSS to the degree of preapplication treatment. The approximate BOD values can be calculated by multiplying the TOC values by 0.54 (5). Figures 2c and 2d indicate that increasing the level of preapplication treatment also decreases the effluent concentrations of TKN and ammonia nitrogen. Nitrate nitrogen (Figure 2e) is the opposite of the other parameters in their relationship to preapplication treatment in that the higher the degree of preapplication treatment, the higher the concentration of nitrate nitrogen, as nitrate nitrogen is the dominant form of nitrogen in a well operated overland flow plot.

The concentration of TP in the overland flow effluent appeared not to follow any trend with preapplication treatment (Figure 2f). The TP concentration increased as the hydraulic loading rate of the wastewater applied was increased at all levels of preapplication treatment (Figures 3f and 4f).

The effluent concentrations of TSS and TOC show no appreciable difference between the high and low loading rates of the same degree of preapplication treatment (Figures 3a, 3b, 4a, 4b). Ammonia nitrogen, as shown in Figure 3c, indicates a dependence on hydraulic loading of the primary treated wastewater, while this was not observed in the secondary (Figure 4c) at the hydraulic loading rates used during this study. This was also true of the TKN (Figures 3d and 4d). A reversal of these trends was observed in the nitrate nitrogen. The nitrate concentration was more hydraulically dependent with the secondary wastewater (Figure 4e) than the primary wastewater (Figure 3e).

HORIZONTAL DISTANCE DOWN SLOPE STUDY

Sampling cups were installed down the slope of the treatment plots at approximately one-third and two-thirds of the length of the overland flow plots. The cups were sampled periodically to evaluate the quality change of the waste water as it transversed the treatment plot. The samples were grab samples taken at peak flow. The data presented cover a period from December 1978 to September 1979. The hydraulic loading rates for raw, primary, and secondary were 20, 20, and 40 centimeters per week, respectively, with the same application cycle as in the pretreatment studies.

The major reduction of TSS occurred in the upper portion of the treatment plot regardless of the degree of preapplication treatment (Figures 5a, 6a, and 7a). This was also true of the organic carbon on the raw and primary plots (Figure 5b and 6b), but not as evident on the secondary (Figure 7b) which does not contain as high a concentration of easily oxidizable organic carbon.

Figures 5c, 5d, 6c, 6d, 7c, and 7d illustrate the nitrification and denitrification reactions which take place in an overland flow treatment plot. The raw and primary show increasing concentrations of nitrate nitrogen with increasing distance down slope during the winter and spring. With an increase in ambient temperature the denitrification rate increases and the nitrate nitrogen does not increase with distance or contact time. This is theorized to be controlled by oxygen transfer and biological activity. Other investigators have also observed this activity (5, 7, 8). The secondary does not show this marked reduction of the oxidized form of nitrogen. Again, this could be oxygen transfer and no readily available energy source for biological denitrification. The nitrification and volatilization reactions of ammonia nitrogen appeared to take place in the upper portion of the slope (Figures 6c and 7c), with the primary and secondary wastewater. These reactions continue throughout the entire length of treatment plot applied with raw wastewater (Figure 5c). The ammonia nitrogen removal mechanisms (nitrification processes) do not appear to be as temperate dependent as those for nitrate nitrogen removal (denitrification process). Figures 5e, 6e, and 7e, show the TN removal with respect to preapplication treatment and horizontal distance downslope. TN considerations involve both the nitrification and denitrification reactions and processes which have been discussed previously.

CURRENT STUDIES

Dissolved Oxygen

The dissolved oxygen content of the effluent from the treatment plots is very temperature dependent and also appears to be dependent on the time into an application cycle as shown in Table 7. The application cycle had begun on June 9 at 7 a.m. after being off for one day rest. Wastewater is applied 6 days a week from 7 a.m. to 7 p.m. Preliminary data indicate the dissolved oxygen concentration varies with the degree of preapplication treatment and with the distance downslope. The dissolved oxygen measurements have varied from a high of 8.6 mg/l in the spring to 3.0 mg/l in summer.

TABLE 7. DISSOLVED OXYGEN CONCENTRATION IN EFFLUENT FROM TREATMENT PLOT

Time		Temp °C	Primary 30 cm/wk D.O. mg/l	Primary 20 cm/wk D.O. mg/l
6/9	10:00 a.m.	24	5.9	7.8
6/10	10:00 a.m.	24	5.4	4.4
6/11	10:00 a.m.	24	4.0	3.2
6/9	2:30 p.m.	32	4.0	4.4
6/10	2:30 p.m.	34	4.2	4.8
6/11	2:30 p.m.	31	4.2	4.8

Rainfall

Effluents from the treatment plots were sampled twice during rainfall events during the application cycle (Table 8). The effluent concentration shows no more variation than normal daily fluctuation, but if the discharges were calculated on a mass basis related to flow a substantial change in the effluent parameters would be observed.

TABLE 8. PLOT EFFLUENT DURING TWO RAINFALL EVENTS WITH APPLICATION OF WASTEWATER

	Concentration, mg/1							
	TSS	BOD	TOC	TP	NO_3	NH_3	TKN	TN
Primary								
30 cm/wk								
1.42 cm	9	13	24	5.3	1.9	0.4	5.7	7.6
1.70 cm	10	13	12	5.0	2.8	3.4	5.5	8.3
20 cm/wk								
1.42 cm	11	14	18	5.0	4.6	0.3	3.1	7.7
1.70 cm	19	8	11	5.1	5.0	0.6	2.8	7.8
Secondary								
25 cm/wk								
1.42 cm	4	9	17	5.8	6.0	0.2	2.7	8.7
1.70 cm	14	7	10	6.0	6.7	0.6	2.5	9.2
40 cm/wk								
1.42 cm	4	7	17	6.0	8.7	0.3	2.5	10.7
1.70 cm	16	10	11	6.1	8.4	0.2	2.3	11.2

The impact of an intense rainfall event during a drying cycle is shown in Table 9. The overland flow plots had been taken off cycle and were in the process of mowing and grass removal. There had been several small rainfall events but none of sufficient intensity and duration to create a runoff from the treatment plot. On May 29, 1980 a rainfall event lasted three hours; 5 centimeters of precipitation fell causing runoff from the treatment plots. The effluents or leachates were all straw colored and would exceed most discharge permits based on effluent concentration. These effluents, because of their high organic carbon, were extracted and analyzed by a gas chromatography-mass spectrometer system. There were very few compounds found using routine gas chromatography. The reason for this is that, in general, gas chromatography is suitable for compounds which are volatile at reasonable temperatures (below 350°C) or from which volatile derivatives can be readily formed. Therefore, compounds that are usually not amenable to gas chromatography include man-made polymers, biopolymers, high molecular weight biological materials such as proteins, nucleic acid, phosphonucleotides and carbohydrates. Also included are drugs, steroids, vitamins, large molecular weight polynuclear aromatics, organic sulfonates (used in detergents) and natural occurring humic substances.

TABLE 9. RAINFALL LEACHATE FROM OVERLAND FLOW PLOT DURING DRYING FOR GRASS REMOVAL

	Concentration, mg/l							
	TSS	BOD	TOC	TP	NO_3	NH_3	TKN	TN
Primary								
20 cm/wk	23	42	45	8.9	17.5	2.2	8.9	26.4
30 cm/wk	15	37	53	10.0	8.8	2.3	8.8	17.6
Secondary								
25 cm/wk	20	46	47	10.2	3.5	4.1	11.3	14.8
40 cm/wk	26	38	45	7.0	4.7	2.3	9.1	13.8

Application Cycle

The application cycle for both flow rates (25 and 40 cm/wk) of secondary was changed from the normal 12 hours per day, 6 days per week, to continuous application for 72 consecutive hours and no application for 96 hours (3-day on, 4-day rest). This application cycle was started in June 1980 to try to improve the nitrogen removal efficiency of the treatment plot by altering the application cycle. The preliminary data in Table 10 contain mean values for the applied wastewaters and plot effluent for six observations. The altered application cycle is compared to the normal cycle of the same time period of the preceeding year.

The continuous application cycle did show a 5-percent increase over the normal cycle for TN removal for both hydraulic loading rates. The absence of a carbon source appears to be the limiting factor controlling the denitrification reactions on the treatment plot. The TSS removal percentage reduction of the six-day cycle is 12 and 8 percent higher for the 25 and 40 centimeters, respectively, than the altered cycle. TP also varied from 14 to 5 percent better reduction with the normal cycle.

TOC removal efficiency was 13 percent higher for the continuous application cycle for both application rates although the effluent concentrations were approximately the same.

TABLE 10. PRELIMINARY DATA FOR EFFECTS OF CHANGE IN APPLICATION CYCLE FOR SECONDARY WASTEWATER-MEAN OF 6 OBSERVATIONS

	Concentration, mg/l						
	TSS	TOC	TP	NO_3N	NH_3-N	TKN	TN
Secondary Applied							
*Normal Cycle	18	13	6.5	3.7	7.0	9.3	12.9
*Altered Cycle	25	18	6.8	8.6	6.2	9.6	18.3
25 cm/wk							
Normal Cycle	5	9	5.2	3.0	<0.1	1.6	5.3
Altered Cycle	10	10	6.4	4.6	0.2	1.8	6.5
40 cm/wk							
Normal Cycle	5	9	5.6	4.8	<0.1	1.6	6.4
Altered Cycle	9	10	6.2	5.7	0.7	2.4	8.2
			PERCENT REDUCTION				
25 cm/wk							
Normal Cycle	72	31	20	19	99	83	59
Altered Cycle	60	44	6	47	96	81	64
40 cm/wk							
Normal Cycle	72	31	14	-	99	83	50
Altered Cycle	64	44	9	34	90	75	55

* Normal Cycle (6 day week-12 hours a day)
Altered Cycle (3 continuous day-4 day rest)

Nitrate Nitrogen Flush

The initial runoff of an application cycle from an overland flow treatment plot will be high in nitrate nitrogen regardless of preapplication treatment or hydraulic loading. The concentration of the nitrate nitrogen will depend on the length of the drying cycle. This phenomenon suggests that the retained ammonia nitrogen on the treatment plot is oxidized to nitrate nitrogen during the drying cycle and is not retained on the treatment slope when wastewater is applied. Nitrate is flushed from the plot with the beginning of an application cycle. Figure 8 is an example of the nitrate nitrogen flush. The effluent concentration of nitrate nitrogen is very high for August 1980 for both hydraulic loadings. This is the beginning of an application cycle after four days of drying. The concentration of nitrate nitrogen in the wastewater applied was 7 mg/l. The August 1979 nitrate nitrogen was much lower as the last application cycles had ceased just 12 hours before the start of this application of wastewater containing a nitrate nitrogen concentration of 4 mg/l.

SUMMARY

These synopses of past and present studies for the development of overland flow technology show that this mode of land treatment is a viable alternative for treatment of domestic wastewaters. Overland flow is site specific, but where applicable will provide excellent treatment for raw or primary wastewaters.

The degree of preapplication treatment will depend on land available and effluent requirements. It has been shown that skimmed and comminuted raw wastewater can be applied directly to the treatment plots. The wastewater should be applied with as little pretreatment as possible to make use of the carbon source for denitrification reaction which takes place if nitrogen is to be one of the effluent considerations. Minimal storage should be considered to retard the production of algae (9) as it has proven to be difficult to remove by the overland flow process.

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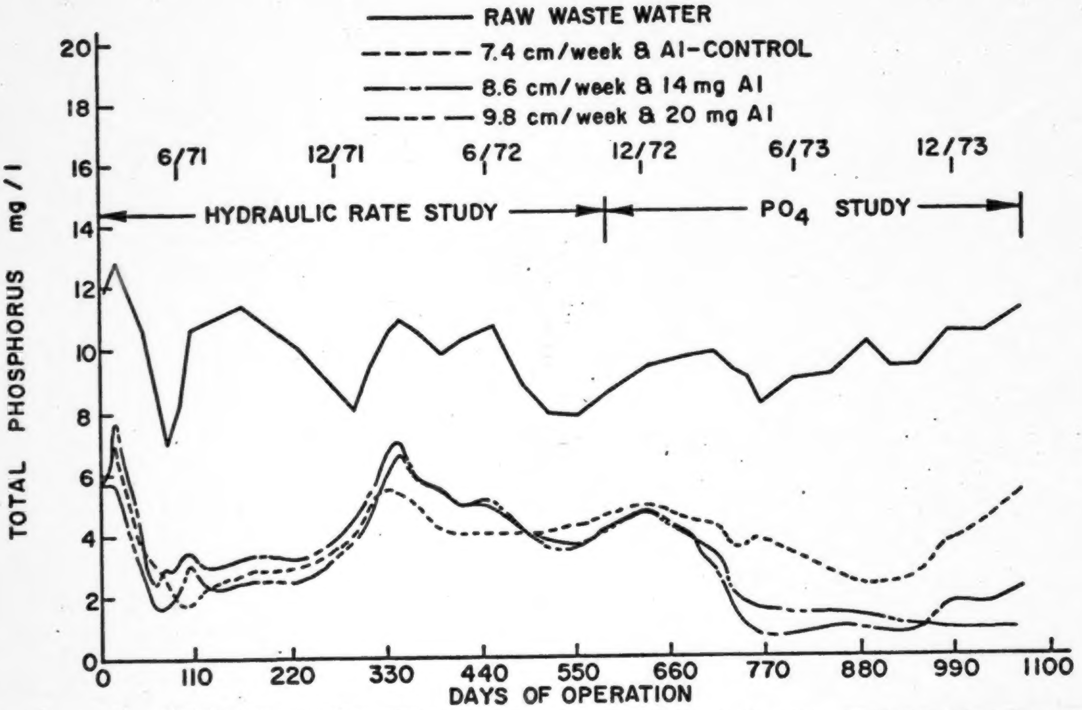

Figure 1. Phosphorus removal during hydraulic study and phosphorus removal study.

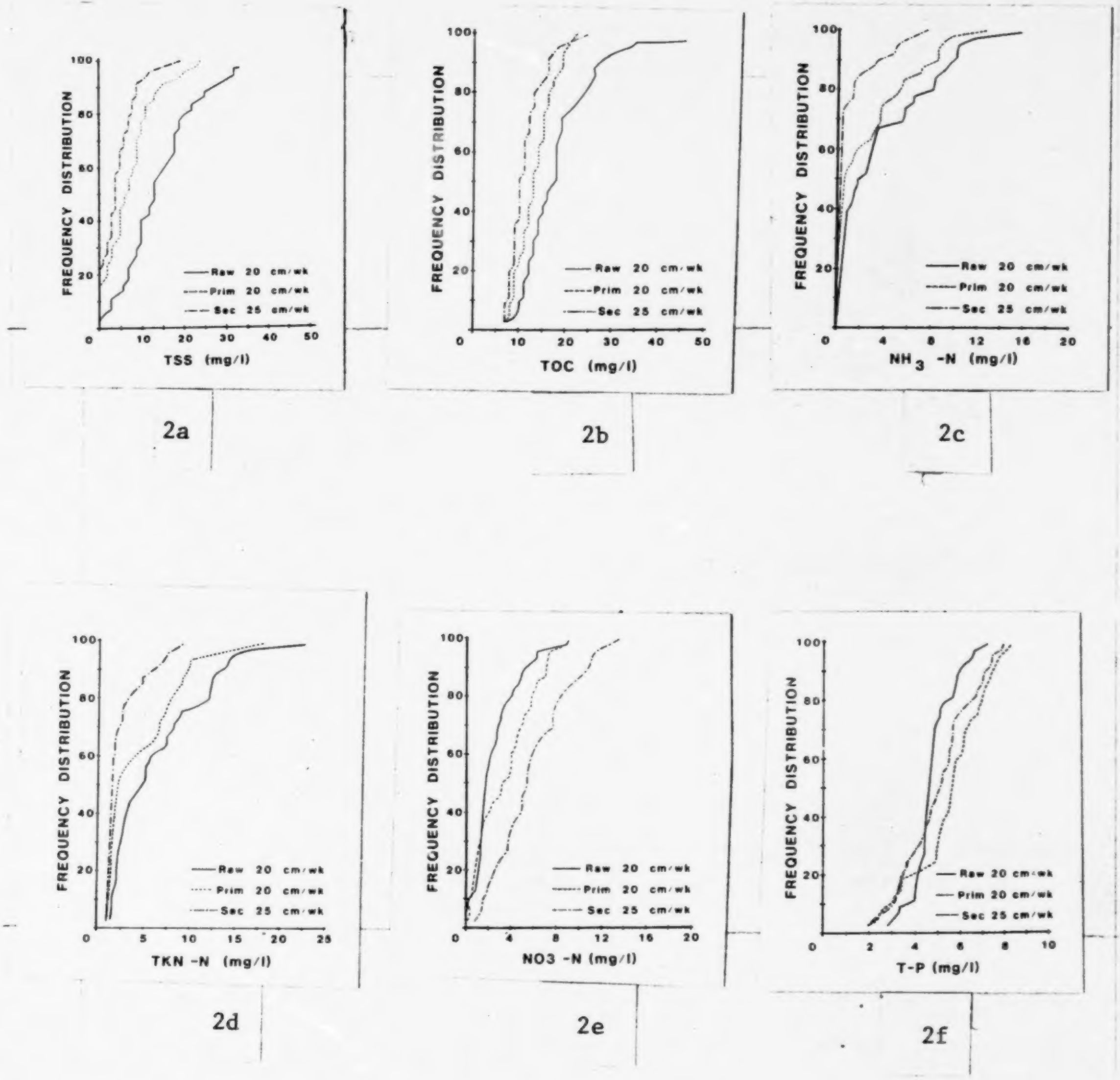

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Figure 2. Frequency distribution of selected parameters related to preapplication treatment and overland flow effluents.

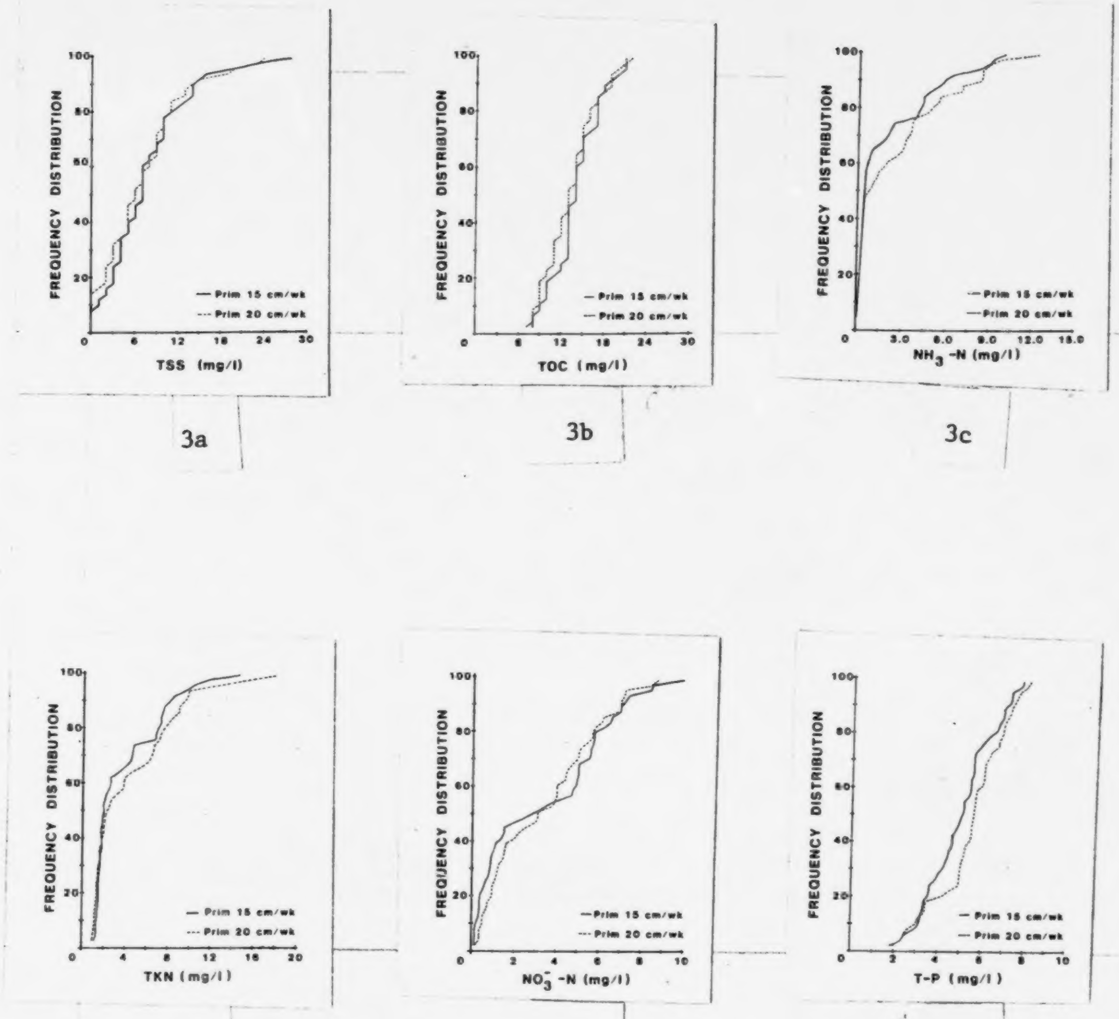

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Figure 3. Frequency distribution of selected parameters related to hydraulic loading of primary treated wastewater and overland flow effluents.

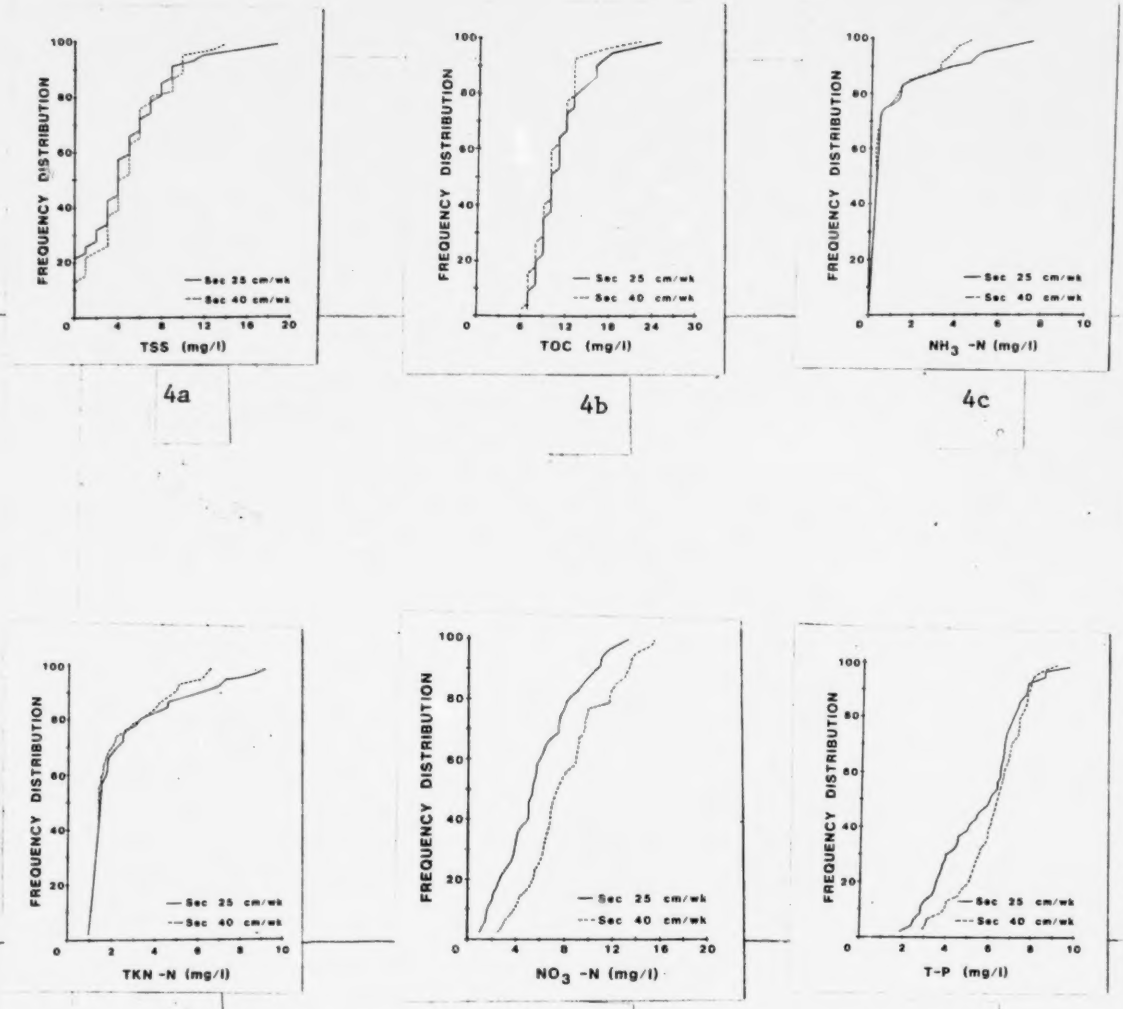

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Figure 4. Frequency distribution of selected parameters related to hydraulic loading of secondary (trickling filter) treated wastewater and overland flow effluents.

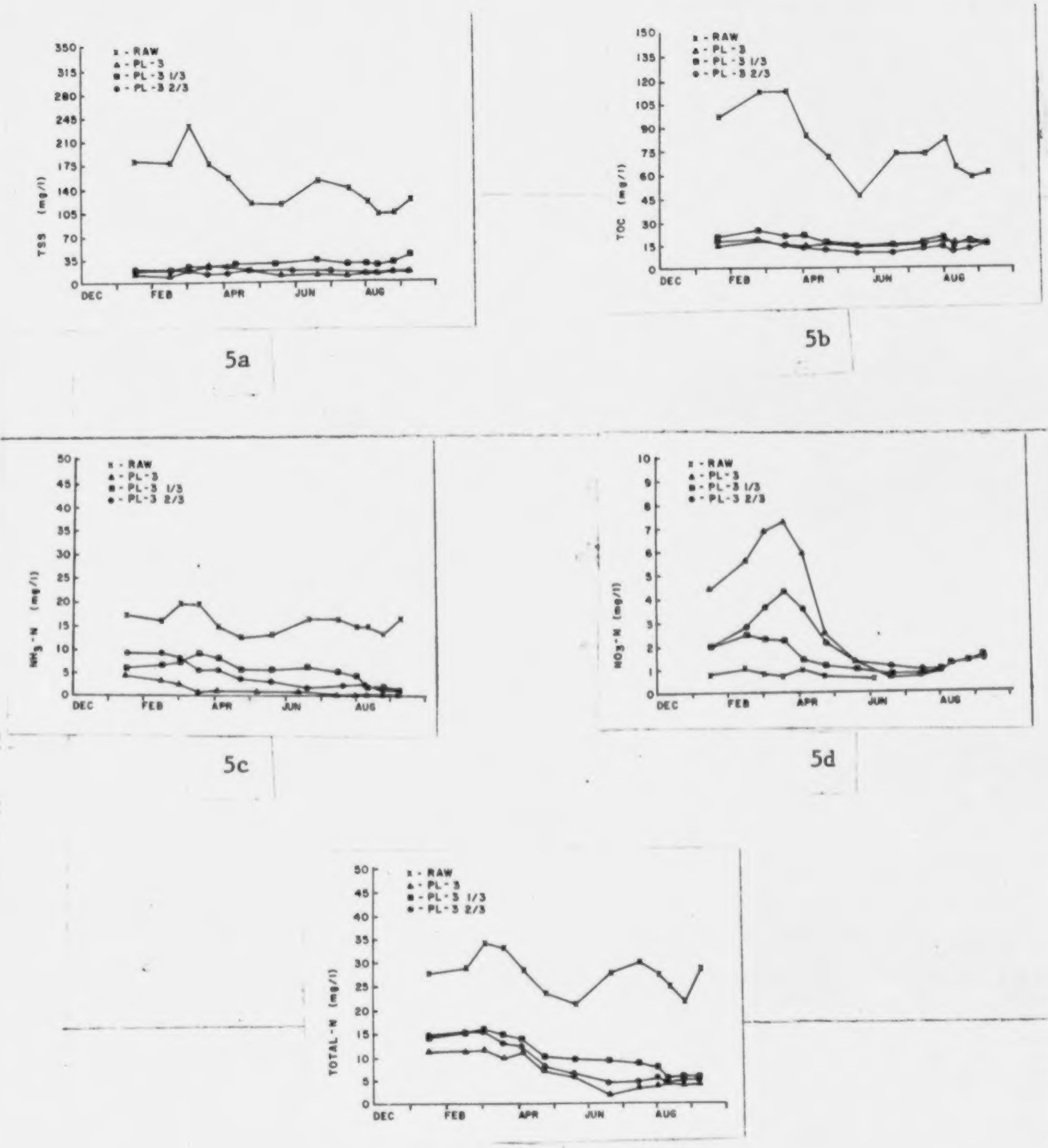

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Figure 5. Raw wastewater and concentration change with distance down slope.

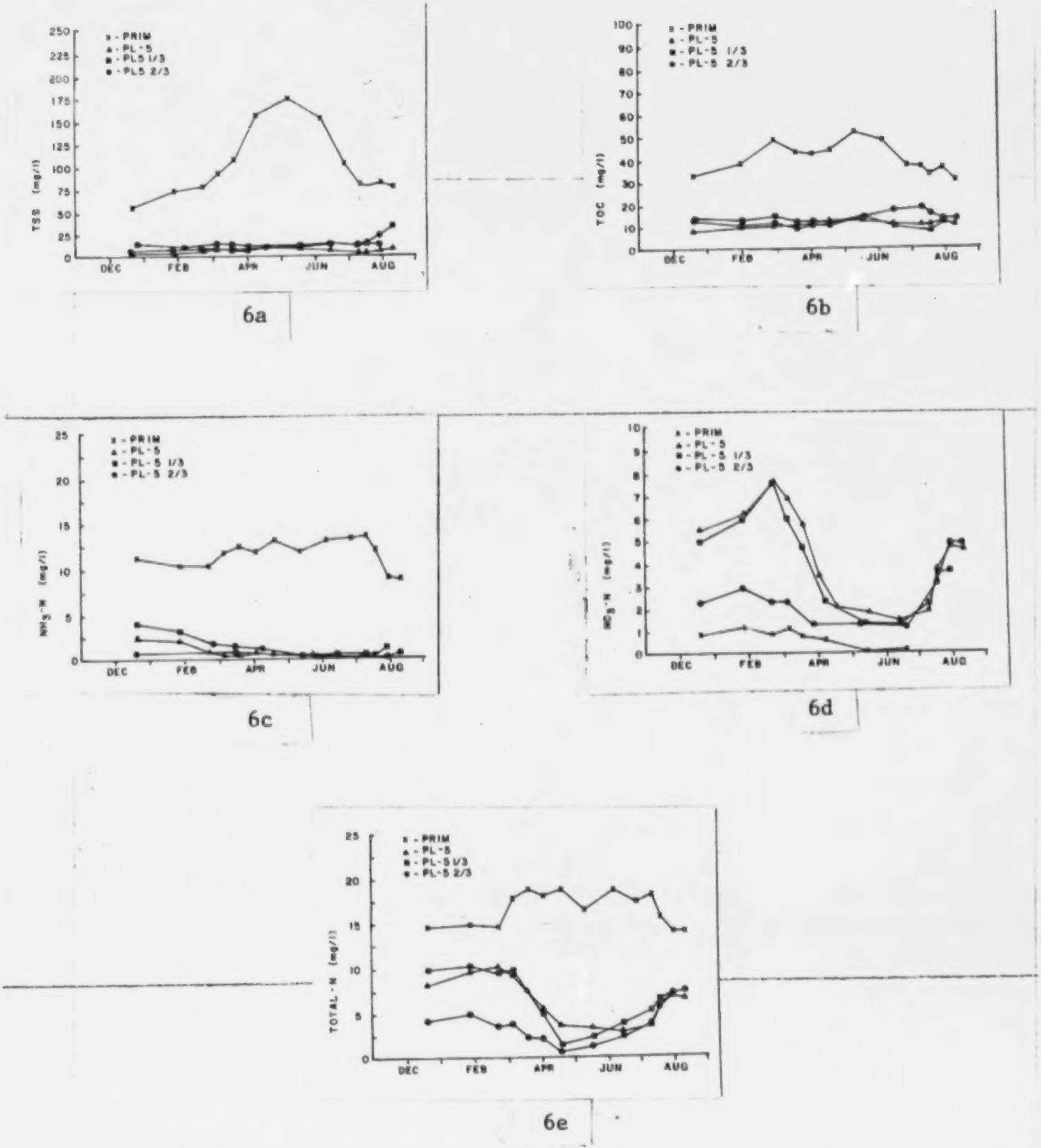

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Figure 6. Primary treated wastewater and concentration change with distance down slope.

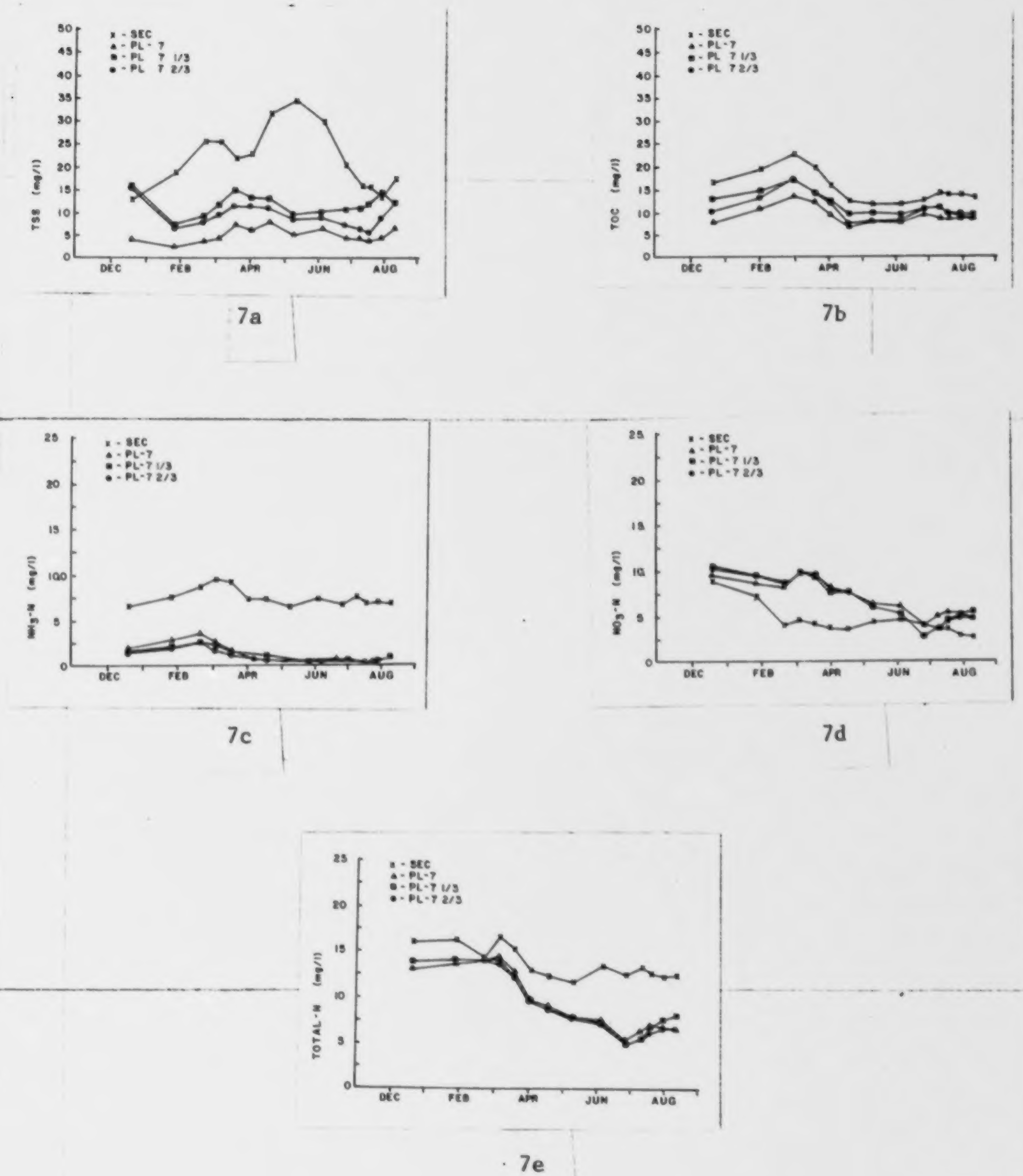

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Figure 7. Secondary (trickling filter) treated wastewater and concentration change with distance down slope.

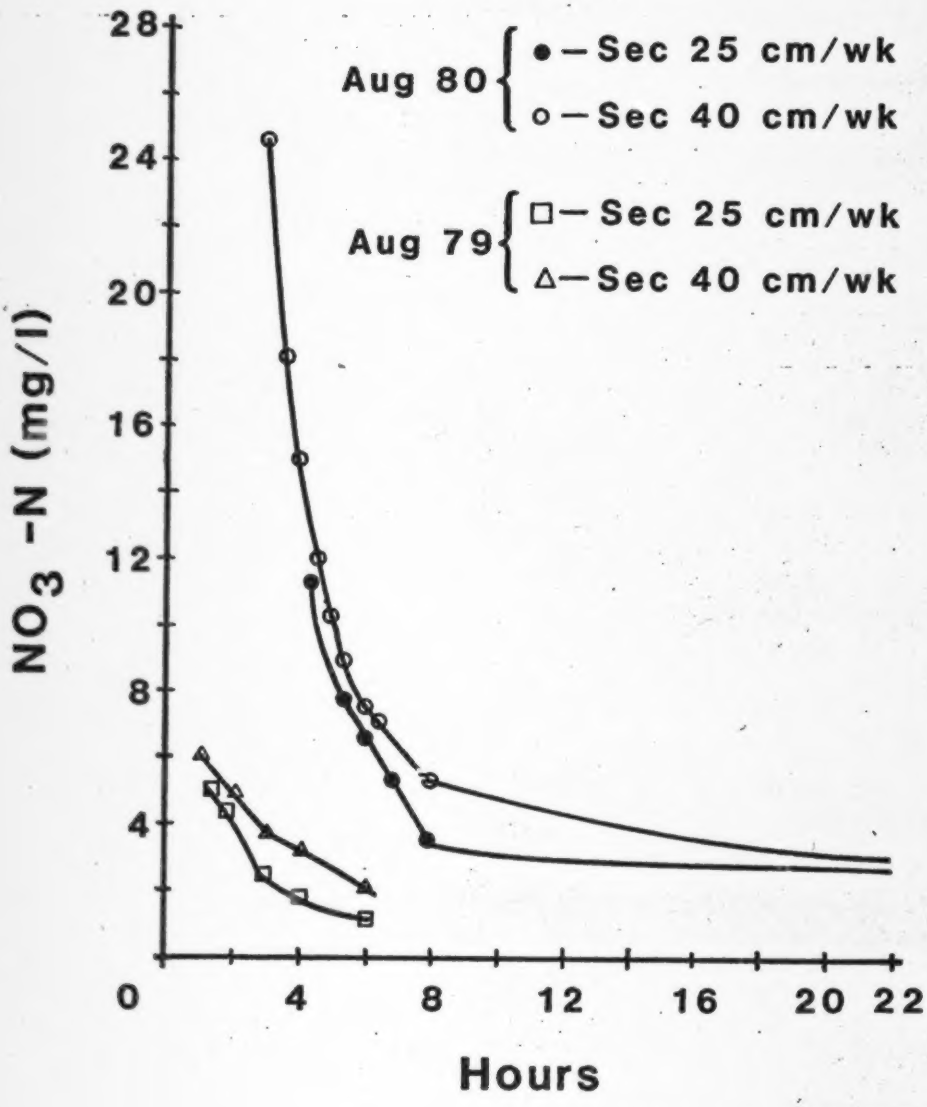

Figure 8. Nitrate nitrogen flush from overland flow plot applied with secondary (trickling filter) treated wastewater with variance in application cycle and hydraulic loading.

Question (by Unidentified Speaker): Did you accumulate any fecal coliform data?

Response (by Mr. Bledsoe): We did monitor this, and with the secondary wastewater we found the lowest coliform concentration.

Question (by Mr. Larry Perry, Frito-Lay Corporation): During the winter operation, how cold do you operate it?

Response (by Mr. Bledsoe): We applied wastewater any time that the risers were not frozen. That meant that there were probably 5 to 10 days during the winter operation that we were not able to apply wastewater. A lot depended upon the maximum and minimum temperatures that occurred during the day.

Question (by Mr. James Alexander, Dan Sherwood & Associates, Inc., Houston, TX): I wanted to know what type of soil you had. Is it sandy loam, clay, or what?

Response (by Mr. Bledsoe): The type of soil indicated by the Soil Conservation Service soil map is a sandy loam, but the underlying subsoil is a clay which makes this specific site suitable for overland flow.

PB82-194317

Overland Flow Treatment of Municipal Lagoon Effluent

C.R. Lee, Soil Scientist
R.E. Peters, Agricultural Engineer
Environmental Laboratory
U.S. Army Engineer Waterways Experiment Station

INTRODUCTION

In 1971, the U. S. Army Corps of Engineers (CE) began an investigation of comprehensive wastewater management on a regional basis. This work was carried out within a cooperative agreement between the Department of the Army and the Environmental Protection Agency (EPA). In addition, the Civil Works Directorate of the Office of the Chief of Engineers requested a technical assessment of land treatment methodologies be provided for use in the CE Wastewater Management Program. This assessment (1) revealed a number of areas of insufficient information for proper implementation of land treatment systems. The U. S. Army Cold Regions Research and Engineering Laboratory (CRREL), Hanover, New Hampshire, was given the responsibility to develop a research program entitled, "Soil as a Purification Medium for Wastewater." This program was designed to provide the necessary information for the proper design and operation of land treatment systems. The overland flow research project at the Waterways Experiment Station (WES), Vicksburg, Mississippi was part of this Wastewater Research Program.

Research was initiated in 1972 at the WES in the form of greenhouse model studies to evaluate overland flow for treatment of municipal secondary wastewater. These early studies revealed that overland flow was very effective in treating secondary wastewater for the removal of nitrogen and heavy metals (2,3,4). Treatment for phosphorus was moderately effective.

At that time overland flow was considered to be a reliable form of advanced wastewater treatment, and implementation of a number of cost-saving improvements appeared to be possible. To this end both the CE and EPA have conducted complementary research on prototype overland flow systems. Major research was conducted by the CE-WES at Utica, Mississippi, and by CE-CRREL, Hanover, New Hampshire, and by EPA at Ada and Pauls Valley, Oklahoma, and Easley, South Carolina.

The WES project near the small rural community of Utica, Mississippi (population 1,000) was jointly funded by EPA and the CE. It was conducted in cooperation with the town of Utica and a local landowner.

EXPERIMENTAL DESCRIPTION

The Utica research facility consists of 24 plots, each measuring 4.5 x 45 m, constructed on slopes of 2, 4, and 8 percent, with eight plots on each slope. This experimental design enables duplication of four different modes of operation on each slope at any one time for a comprehensive evaluation of overland flow treatment of wastewater. Specific characteristics of the facility are presented in Table 1.

TABLE 1. CHARACTERISTICS OF THE OVERLAND FLOW FACILITY AT UTICA, MISSISSIPPI

Climate:	Precipitation:		Rainfall 137 cm per year
			Snow and sleet 5 cm per year
	Temperature:	Maximum:	mean annual 24°C
			extreme 41°C
		Minimum:	mean annual 12°C
			extreme -20°C
Soil:	Type:		Loess--Grenada silt loam (Gloffic Fragiudalf)
	Permeability 0.042 cm per hour		
	Moisture content:		1/3 bar 23.0%
			15 bar 9.9%
	Cation exchange capacity:		10 meq/100 g
	pH 7.0		
Vegetation:	Grass mixture--5:2:2:1 of reed canary (*Phalaris arundinacea* L.), Kentucky 31 tall fescue (*Festuca arundinacea*), perennial ryegrass (*Lolium perrene* L.) and common Bermuda (*Cynodon dactylon* L.), respectively		
Lagoon effluent:	Suspended solids 30 mg/ℓ, ranging from 1-109 mg/ℓ		
	BOD 22.0 mg/ℓ, ranging from 6-61 mg/ℓ		
	Total N		18.0 mg/ℓ*
	NH_4-N		13.0 mg/ℓ*
	NO_3-N		0.4 mg/ℓ
	Total P		9.2 mg/ℓ*
	Ortho-PO_4-P		7.9 mg/ℓ*
	Zinc		0.339 mg/ℓ*
	Copper		0.120 mg/ℓ*
	Nickel		0.141 mg/ℓ*
	Cadmium		0.077 mg/ℓ*
	pH		7-11

*Amended to this concentration as required.

Factors evaluated were wastewater application rate (0.071 to 0.847/cm hr), period (6, 18, 24 hr), and frequency (5 or 7 days/week); slope; removal efficiency of biochemical oxygen demand (BOD), suspended solids, algae, nitrogen (N), phosphorus (P), heavy metals, and fecal coliforms; effects of storm events and crop management.

Wastewater applied to the research plots was obtained from a 2.4-ha facultative lagoon. The effluent was pumped from the lagoon to a central holding tank prior to distribution to individual plots. Since the lagoon was underloaded, additional inorganic nitrogen and phosphorus were added as a supplement to make the applied wastewater more representative of secondary municipal effluent strength. To allow an assessment of the ability of overland flow to remove heavy metals, a heavy metal injection system was used to add selected amounts of copper (Cu), nickel (Ni), cadmium (Cd), and zinc (Zn). The applied lagoon effluent characteristics as amended are given in Table 1.

The amended wastewater was surface applied to each plot through a trough fashioned from a rain gutter. Holes in the bottom of the gutter allowed water to be distributed uniformly across the top of each plot. Wastewater application periods were regulated through a bank of time clocks controlling electrically activated solenoid valves. The amount of wastewater applied in each period was regulated by a manually operated ball valve for each plot.

Peristaltic pumps were used to apply aluminum sulfate or alum to four plots on each of the three slopes to promote phosphorus reduction. The alum contained 9.1 percent aluminum and was applied in a 1:1-mole ratio of alum: phosphorus (9.6:1 weight ratio of alum:phosphorus). The alum was pumped from a stock solution and added directly into the applied wastewater stream as it entered the application trough. Runoff was collected in a sump at the lower end of each plot and pumped through the meter for a record of cumulative runoff. Stormwater runoff was measured using a 5.08-cm Parshall flume and Leupold Stevens Type F water level recorder. A modified ISCO Model 1680R refrigerated water sampler was used to sample rainfall runoff. More details of the specific modifications have been published elsewhere (5). Additional details of experimental procedure have been described elsewhere (6).

RESULTS

Runoff Volume

The volume of runoff measured from a wastewater application of 0.21 cm/hr for 6 hours, 5 days/week averaged a low of 53 percent of the applied volume during the hot summer months and reached a high of 78 percent of the applied volume during the cold winter months (Figure 1). Similar volumes of runoff were observed throughout the year for both the 2- and 8-percent slopes.

When wastewater application was continuous at 0.11 cm/hr for 24 hr, 7 days/week, the difference between summer and winter runoff volumes became similar and averaged between 80 to 90 percent of the applied volume (Figure 2). Intermittent wastewater application periods of 6 and 18 hr showed significantly less summer runoff volumes than during the winter months.

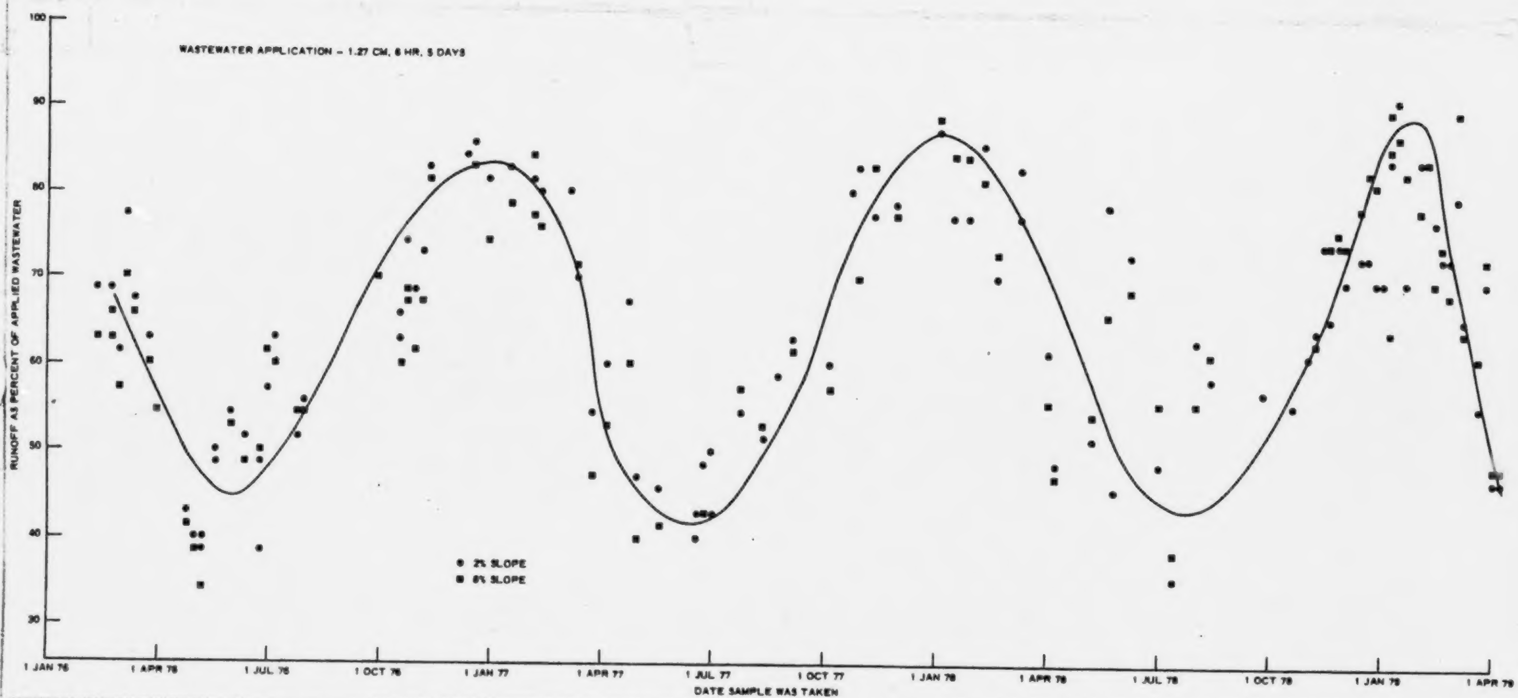

Figure 1. Percent runoff from the 2% and 8% slopes.

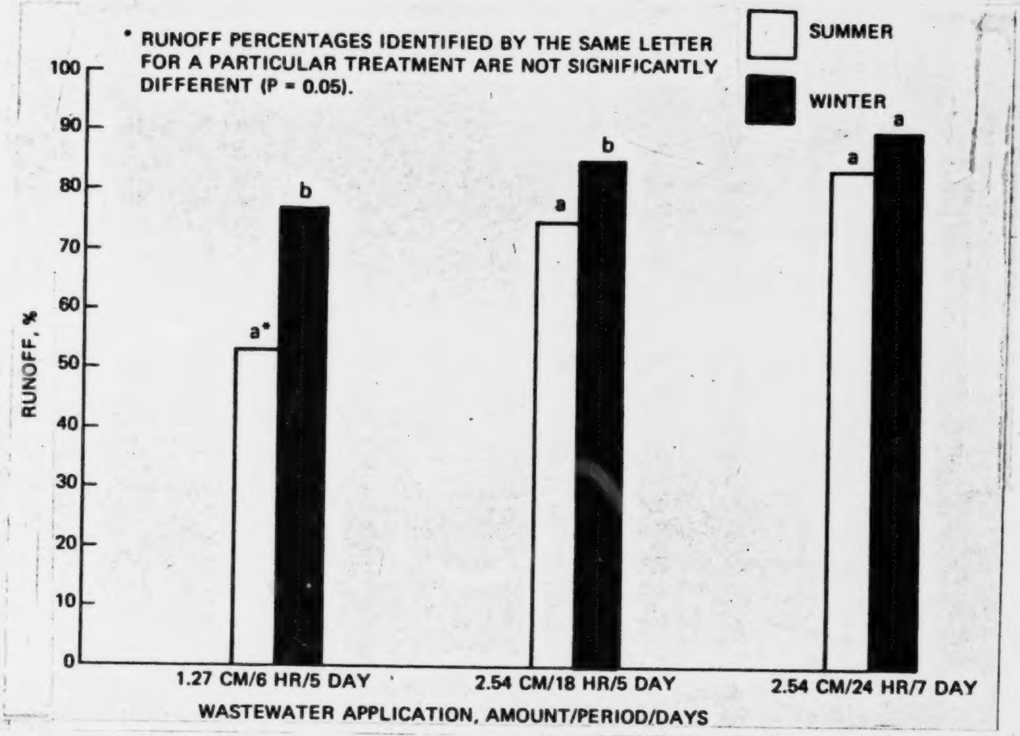

Figure 2. **Runoff expressed as a percentage of applied wastewater for summer and winter conditions at three wastewater treatments.**

Water pH After first page, use this line for manuscript)

The pH of the lagoon effluent increased to as high as pH 10.8 from a low of pH 7.2 during the month of February (Figure 3).

Injection of additional nitrogen and phosphorus as ammonium phosphate and ammonium chloride in liquid form reduced the pH of the lagoon effluent during the months of May-December before the wastewater was applied to the treatment slope. Runoff water pH was observed to be 8.5 or below and averaged pH 7.5 during the summer and fall.

These data indicate that overland flow has the capacity to reduce the pH of applied wastewater to pH 8.5 or below.

Wastewater Application Depth

An analysis to determine the effect of wastewater application depth or amount was made by setting slope and period of application constant and varying the daily amount of wastewater applied. Wastewater was applied at 1.27, 2.54, 3.81, and 5.08 cm, 18 hr, 5 days/week to eight plots on the 4-percent slope. The data were collected during the period beginning 27 September 1977 through 4 April 1979.

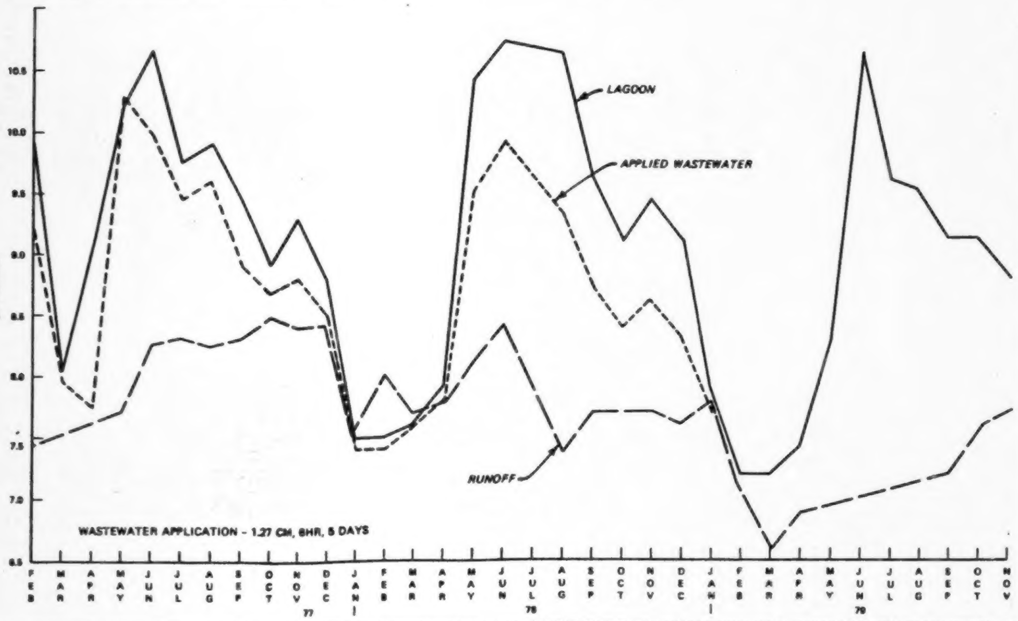

Figure 3. Seasonal pH trends at the Utica overland flow system.

Five-Day Biochemical Oxygen Demand (BOD_5) and Total Suspended Solids (TSS)--

Runoff BOD_5 concentrations and reduction efficiencies ranged from 3.5-7.2 mg/ℓ and 74-95 percent, respectively, when the depth of wastewater applied ranged from 1.27-508/ cm/18 hr period (Figure 4). Similarly, TSS concentrations and reduction efficiencies ranged, respectively, from 5.2-12.7mg/ℓ and 71-93 percent. The results indicate a tendency to increase runoff concentrations (although not statistically significant) and to decrease efficiencies of reduction for both BOD_5 and TSS when the depth of applied wastewater was increased from 1.27 to 5.08 cm.

Nitrogen--

Concentrations of total Kjeldahl nitrogen (TKN) in the overland flow runoff were about 5 mg/ℓ or less at all four depths of wastewater application (Figure 5). The lowest runoff TKN concentration, about 3.3 mg/ℓ, occurred for the 1.27 cm/18 hr depth and was significantly different from the remaining depths of wastewater application. The data indicate that runoff TKN concentrations leveled off at rates greater than 1.27 cm up to 5.08 cm/18 hr, and were not statistically different from each other. Reduction efficiencies for TKN ranged from a high of 89 percent at the lowest depth of wastewater application to a low of 76 percent at the highest rate of application. The percent reduction of TKN for the 1.27 cm, 18 hr wastewater application was statistically different from the other three depths of application but the 2.54, 3.81, and 5.08 cm, 18 hr applications were not different from each other. The average TKN concentration in the applied wastewater during the period of this study was 20.5 mg/ℓ.

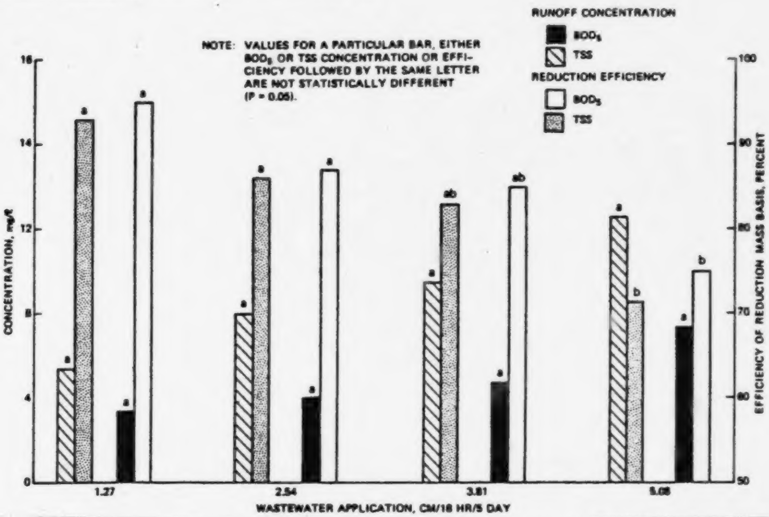

Figure 4. Effect of wastewater application on reduction of BOD_5 and TSS.

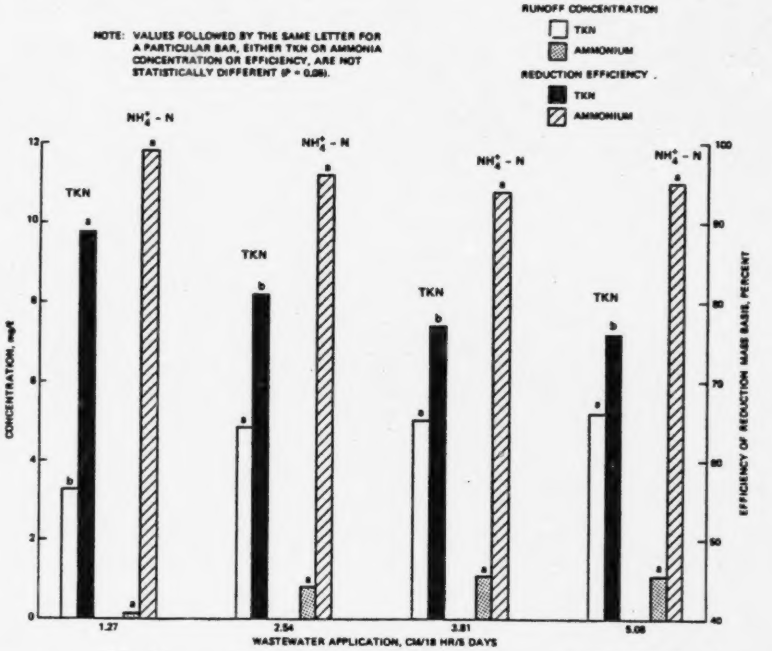

Figure 5. Effect of depth of wastewater application on reduction of TKN and ammonium.

Ammonium was effectively reduced ranging from about 99 percent at the 1.27 cm, 18 hr wastewater application to about 95 percent at the 5.08 cm, 18 hr application. Ammonium concentrations in the runoff ranged from a low of about 0.1 mg/ℓ to as high as 1.1 mg/ℓ. Differences in efficiency of ammonium reduction and runoff concentrations at the four depths of wastewater application were not statistically significant. Average ammonium concentration in the applied wastewater during the study was 15.6 mg/ℓ.

Average runoff nitrate-nitrogen (NO_3^--N) concentrations were 1.0, 2.6, 3.8, and 4.8 mg/ℓ for wastewater application depths of 1.27, 2.54, 3.81, and 5.08 cm, applied in 18 hr, respectively. Nitrate-nitrogen appears to increase in the runoff from a period of about October through February, which coincides with colder temperatures. Up to 15 mg/ℓ, NO_3^--N was observed during January from the 5.08 cm, 18 hr application. At the same time up to 8 mg/ℓ NO_3^--N was observed in the runoff from the 1.27 cm, 18 hr application. Since applied wastewater NO_3^--N averaged less than 1 mg/ℓ the occurrence of significant nitrification on the plots is readily apparent. However, because of cooler temperatures denitrification and crop uptake proceed at much slower rates resulting in increased NO_3^--N in the runoff. Efficiencies of NO_3^--N reduction are difficult to interpret since negative efficiencies often result from the combined effects of low applied levels of NO_3^--N, and nitrification on the plots producing higher runoff concentrations.

Phosphorus--

The effect of depth of wastewater application on reduction of total phosphorus is shown in Figure 6. It is apparent from these results that

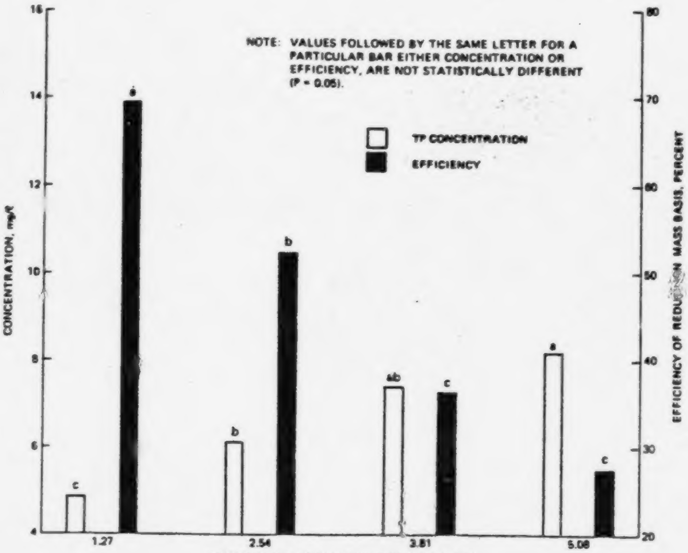

Figure 6. Effect of depth of wastewater application on reduction of total P.

phosphorus is not as efficiently treated by overland flow as is nitrogen. Because of the nature of overland flow where water flows over the soil surface rather than through the soil profile, there is limited opportunity for phosphorus to be adsorbed and removed from the applied wastewater. Concentrations of total phosphorus in the runoff increased from about 4.8 mg/ℓ to 8.2 mg/ℓ when the depth of wastewater application was increased from 1.27 cm to 5.08 cm/18 hr. At the same time efficiency of reduction decreased from about 68 percent to 42 percent. Almost all the total phosphorus content was inorganic or ortho-P and the same general observations were found for reduction of ortho-P as for total phosphorus. The average applied wastewater concentration of total phosphorus during this period of study was 10.3 mg/ℓ.

Heavy Metals--

Overland flow is exceptionally efficient in the removal of heavy metals from applied wastewater. Heavy metals were applied to the treatment plots for 18 months. During this period the concentration of Cd, Cu, Ni, and Zn in the applied wastewater was maintained by metal salt additions at 0.077, 0.120, 0.141, and 0.339 mg/ℓ, respectively. These concentrations were selected as being closer to the average concentrations of these metals found in wastewaters reported in the literature (7, 8, 9, 10). Runoff water for a wastewater application of 1.27 cm, 6 hr, 5 days contained 0.0020 mg/ℓ Cd, 0.0304 mg/ℓ Cu, 0.0103 mg/ℓ Ni, and 0.055 mg/ℓ Zn. These concentrations represented removal efficiencies of 88.2, 84.0, 94.4, and 86.6 percent for Cd, Cu, Ni, and Zn, respectively.

Temperature Effects

Nitrogen--

Air temperatures were poorly correlated with runoff concentrations and reduction efficiencies for both nitrogen and phosphorus. This was true for all regressions and is not surprising since air temperature is not indicative of the temperature at the soil surface where most of the microbiological activity is believed to take place. A more useful indicator of nitrogen treatment on overland flow systems is soil temperature. The 8-percent slope had a significantly higher soil temperature than the 2-percent slope (Figure 7). The higher temperature on the 8-percent is probably due to the southern exposure of the 8-percent slope during the winter compared to the 2-percent slope. Consequently, the 8-percent slope produced significantly higher grass yields than the 2-percent slope. The increased grass growth on the 8-percent slope resulted in the detention time for a given wastewater application to be similar for both slopes. In many respects, the 8-percent slope treated wastewater as well as or better than the 2-percent slope.

Ammonium was the only constituent exhibiting a meaningful correlation with soil temperature. Figure 8 shows the quadratic regression relating runoff ammonia concentrations to soil temperature, R = 0.83. The quadratic regression relating efficiency of ammonium reduction had a significant correlation, R = 0.86. The relationship between runoff ammonium concentrations and soil temperature is believed to be due to increased activity of soil microorganisms and plant uptake during warmer seasons followed by a lower level of activity during the winter. While average soil temperatures on the 2- and 8-percent

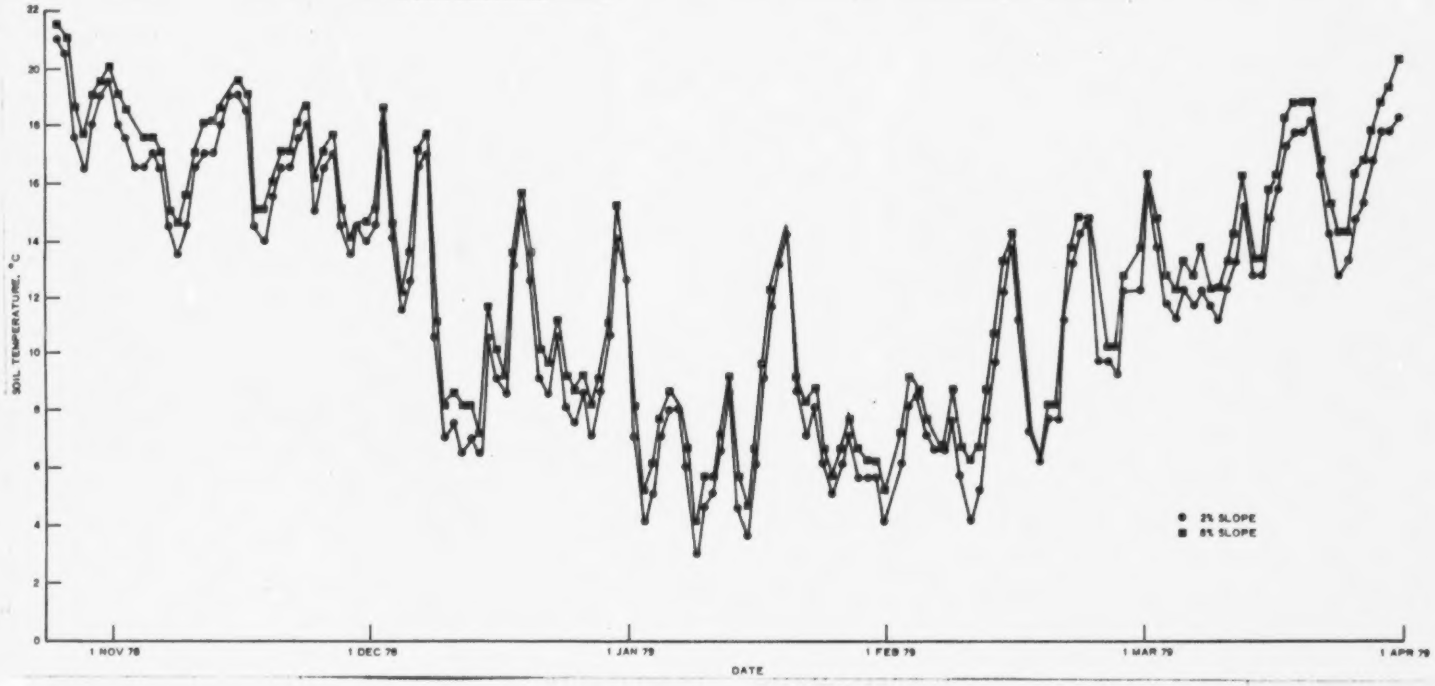

Figure 7. Average soil temperature on two slopes receiving 1.27 cm wastewater applied in 6 hr, 5 days/week.

slopes were significantly different, average runoff ammonium concentrations and reduction efficiencies were not significantly different.

An interesting comparison may be made between the data and equation shown in Figure 8 with similar data from a study of overland flow in cold climates by Jenkins et al. (11). Both data sets indicate a decrease in ammonium treatment at about 13-14°C. However, the equation relating runoff ammonium concentration to soil temperature is considerably different. Further examination of the two curves indicate almost an order of magnitude difference in maximum runoff ammonium concentrations. These differences are probably explained by the higher applied ammonium concentrations in the primary effluent used in the Jenkins (11) study (33 mg/ℓ) as opposed to the lower concentrations in the applied lagoon effluent (12.8 mg/ℓ average) used at Utica.

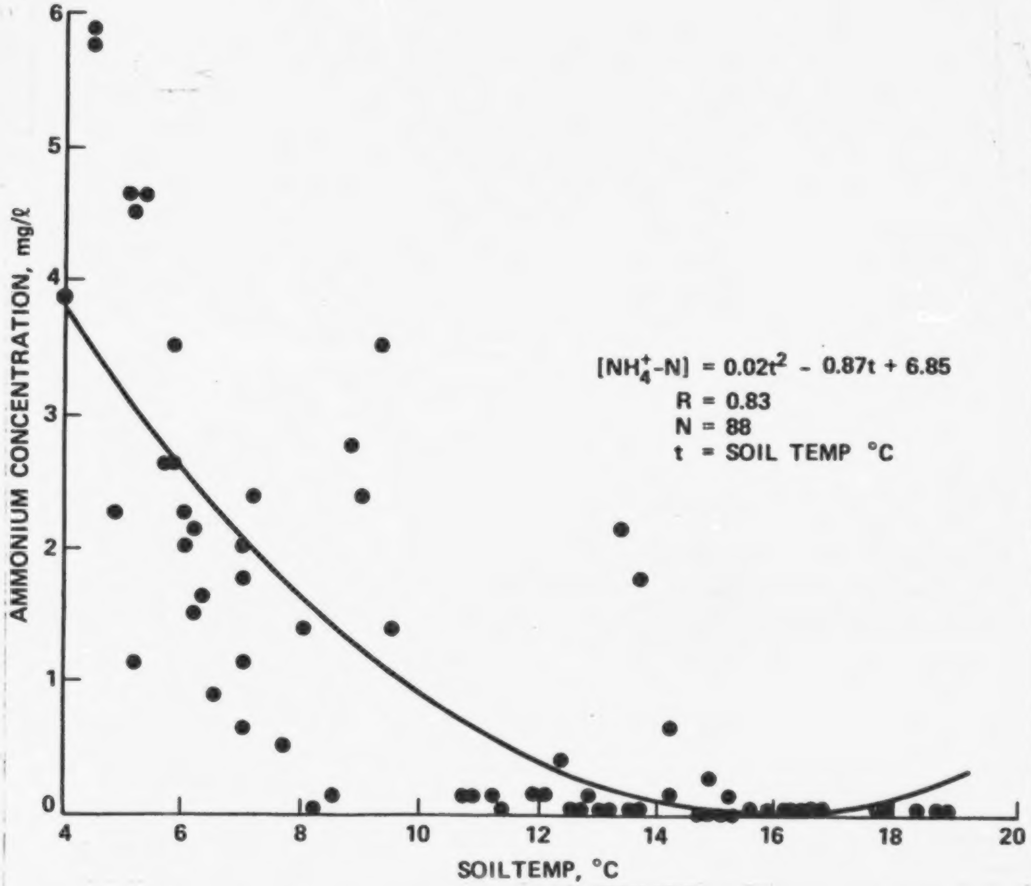

Figure 8. Runoff ammonium concentration as a function of soil temperature.

Runoff NO_3^--N concentrations were only moderately correlated with soil temperature, r = -0.68. According to Webber and Beauchamp (12) fluctuating soil temperatures have a pronounced effect on activities and survival of soil microbial populations. As such, transient flushes from land treatment systems and variation in NO_3^--N may be expected. In this study, runoff NO_3^--N concentrations varied from as low as 0.1 mg/ℓ up to 11 mg/ℓ. Runoff NO_3^--N concentrations greater than 5.0 mg/ℓ occurred at soil temperatures ranging from 5°C up to 15°C. Relationships between soil temperature and runoff phosphorus concentration or phosphorus removal were very poor.

Since there was a general decline in nitrogen treatment during the winter, the depth of wastewater application for two plots on the 4-percent slope was decreased by increasing the application period from 6 to 18 hr. Results indicated an increase in TKN reduction for the winter season from 80 percent up to 93 percent. Ammonia reduction was about 98 percent. When the 1.27 cm, 18 hr treatment was applied 7 days per week rather than 5 days the reduction efficiency for TKN showed a statistically significant decrease from 93 to 91 percent, while concentration remained virtually unchanged at about 2 mg/ℓ. At the same time a slight increase in total phosphorus concentration from 6.0 to 6.9 mg/ℓ and a slight decrease in reduction efficiency from 60 to 45 percent were not significantly different. These data indicate that wastewater may be applied for two extra days per week during the winter provided the application is maintained at 1.27 cm applied in 18 hr.

Interaction of Applied Nitrogen Concentration and Load

A total of 6 plots on the 4-percent slope were used to evaluate nitrogen treatment at different nitrogen concentrations in the applied wastewater and different depths of wastewater applications thus varying the total load of applied nitrogen. TKN concentrations of approximately 10, 25, and 45 mg/ℓ applied in amounts of 2.54, 5.08, and 10.16 cm/24 hr were evaluated. When wastewater applications were held to 2.54 cm applied in 24 hr, runoff TKN concentrations were about 2 mg/ℓ regardless of TKN concentration in the applied wastewater. Conversely, when applied concentrations were held to about 10 mg/ℓ and applications were increased up to 10.16 cm/day, resultant runoff concentrations remained at about 2-3 mg/ℓ. This suggested that total applied load of TKN was important in determining treatment performance. Figure 9 shows runoff TKN concentrations as a function of total applied daily load of TKN. These data indicate runoff TKN concentration of less than 5 mg/ℓ when total daily applied load is less than approximately 240 gm (1.9 kg TKN/ha). By projection, applied daily TKN load could be as high as 400 gm (3.1 kg TKN/ha) and still achieve runoff TKN concentrations less than 5 mg/ℓ.

Since composition and strength of wastewaters differ from site to site, data of this type are useful for estimating overland flow performance for given wastewater characteristics. The analysis should be extended to cover other constituents, particularly BOD_5 and TSS.

Alum addition

An attempt was made to enhance phosphorus removal by adding alum to wastewater prior to land application. This technique was previously used with raw municipal sewage by Thomas et al. (13) and found to be successful in enhancing phosphorus removal by overland flow. An aluminum:phosphorus mole ratio of 1:1 was shown to reduce total phosphorus concentration in the runoff to 1.0 mg/ℓ at Ada, Oklahoma.

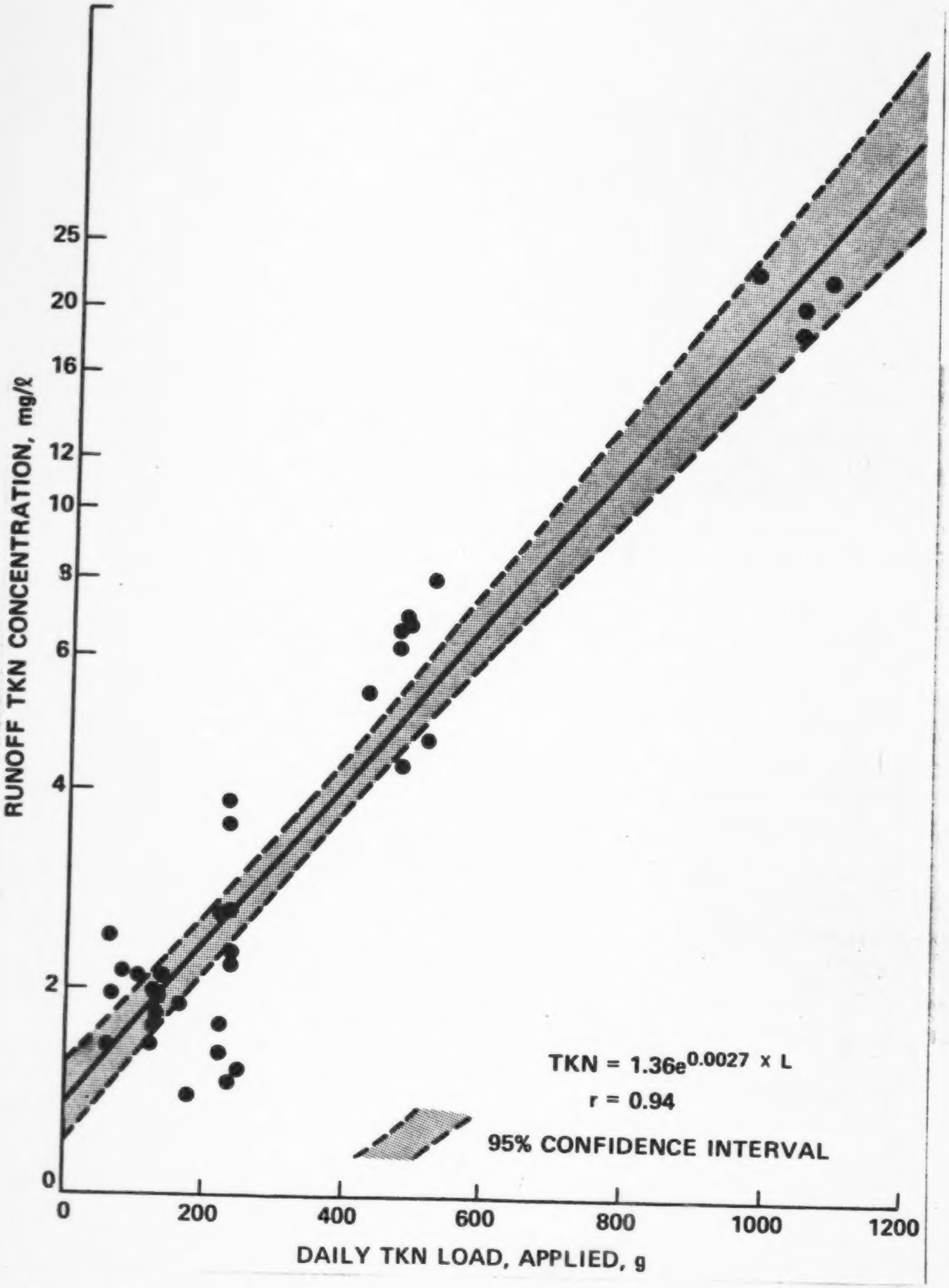

Figure 9. Runoff TKN concentration as a function of total daily applied load.

In this study alum was added directly into the distribution trough at the top of the slope. It was assumed that sufficient mixing of the alum and lagoon effluent occurred in the trough and on the soil surface adjacent to the point of discharge from the trough.

The concentration of phosphorus in the runoff from alum-treated plots was substantially reduced compared to runoff where no alum was applied (Figure 10). Phosphorus concentrations with alum additions were reduced to a minimum of 1.3 mg/ℓ compared to 3.5 mg/ℓ without alum. Wastewater applications were 1.27 cm applied in 6 hr for plots receiving no alum and 2.54 cm applied in 18 hr for plots treated with alum.

Phosphorus removal efficiencies (mass basis) ranged between 65 and 90 percent with the addition of alum to the lagoon effluent as compared to below 50 percent without alum during the months October through March (Figure 10). These results suggest that where phosphorus removal is required, alum may be added during the winter months to maintain removal efficiencies.

The addition of alum to the applied wastewater resulted in precipitation of an aluminum phosphate-aluminum hydroxide sludge. Approximately 40 gm of sludge accumulated for each cubic meter of applied wastewater containing 10 mg/ℓ of phosphorus (14). The continuous buildup of this sludge at a rate of 10 kg/ha/day on the treatment area was observed for 15 months but has not been found to be detrimental to grass growth. There was a tendency for grass on the alum-treated plots to contain slightly lower potassium and phosphorus.

Algae Reduction

During the summer of 1979, a study was conducted to determine the capacity of overland flow to remove algae. Wastewater applied to the overland flow treatment facility at that time contained 41-61 mg/ℓ BOD, 38-109 mg/ℓ suspended solids, 6-12 mg/ℓ TKN, and 3-6 mg/ℓ total phosphorus and having a pH ranging from 8-9. The predominant genera of algae contained in the applied wastewater were Oscillatoria and Arthrospira.

There was a moderate relationship ($p = 0.01$), $r = 0.64$, between percent algae reduction and percent suspended solids reduction. Average values of percent reduction for algae and suspended solids at various application rates are shown in Table 2. While the concentration of suspended solids in the lagoon effluent varied during the study, covariance analyses of the data indicated that this did not significantly affect the concentration of suspended solids observed in the runoff. Reduction of both algae and suspended solids decreased to 75 percent at a wastewater application of 0.84 cm/hr. Results at the U.S. Army Cold Regions Research and Engineering Laboratory overland flow plots have shown 95 percent suspended solids reduction at an application rate of 0.84 cm/hr when applying primary wastewater containing no algae. The presence of algae in the applied wastewater significantly affects the removal efficiency of suspended solids on the overland flow system.

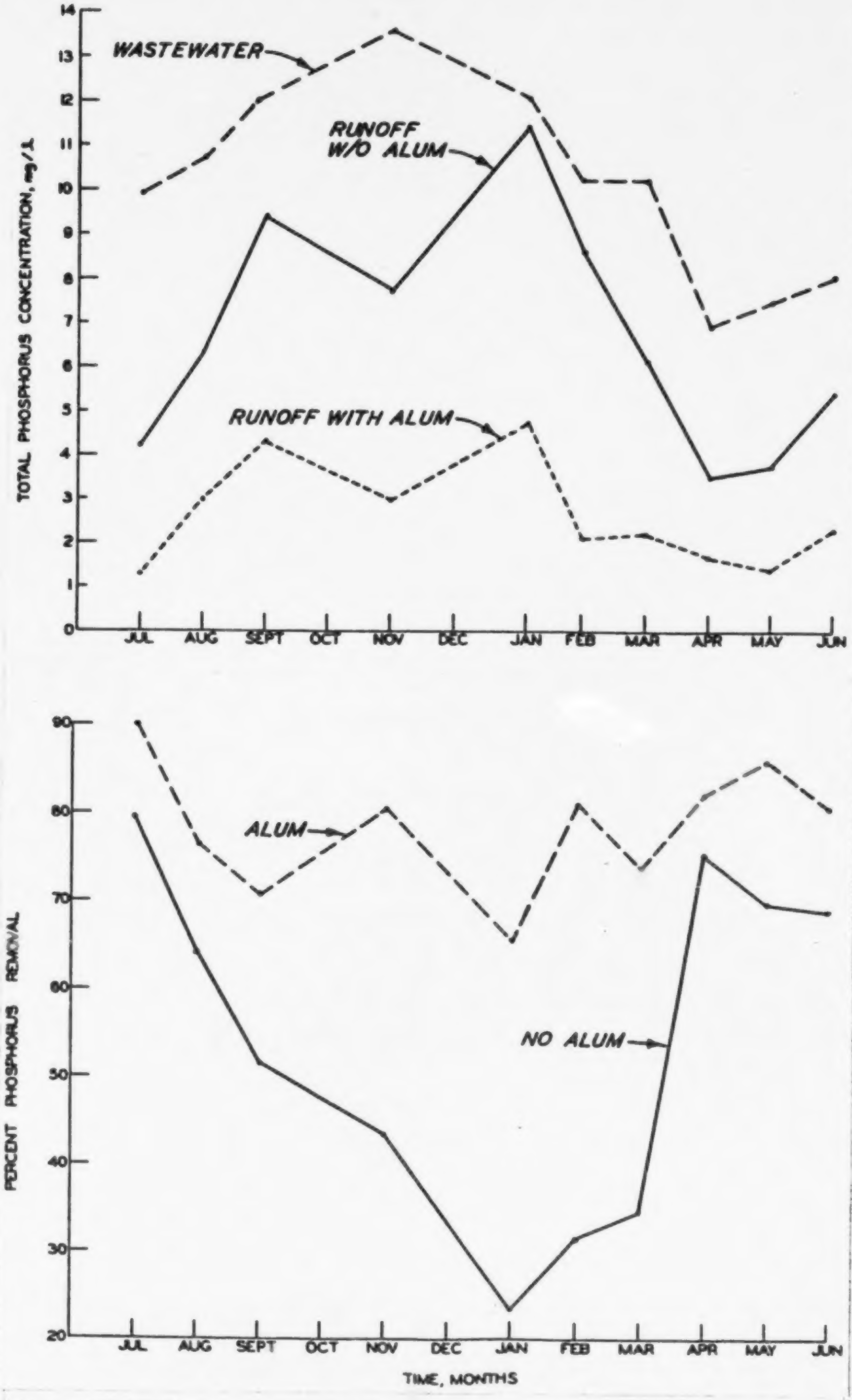

Figure 10. Influence of alum addition on runoff phosphorus concentrations and percent removal from an overland flow land treatment system (15).

TABLE 2. REDUCTION OF ALGAE AND SUSPENDED SOLIDS BY OVERLAND FLOW AT FOUR RATES OF WASTEWATER APPLICATION

	Continuous Rate of Wastewater Application cm/hr			
	0.11	0.21	0.42	0.84
Algae reduction (percent)*	100	100	94	75
Applied suspended solids content (mg/ℓ)†	61	58	65	96
Runoff suspended solids content (mg/ℓ)*	7	2	10	24
Suspended solids reduction (percent)*	89	97	85	75

* Average of 4 replications.

† Average of 2 replications.

A plot of the efficiency of algae reduction versus application rate is shown in Figure 11. The resulting linear regression equations for algae reduction E_a and suspended solids reduction E_{ss} are:

$$E_a = 108.9 - 40.9R \quad r = 0.68 \qquad \text{(Equation 1)}$$

$$E_{ss} = 99.2 - 26.2R \quad r = 0.59 \qquad \text{(Equation 2)}$$

where E_a or E_{ss} is the percent reduction of algae or suspended solids and R is the rate of wastewater application in centimeters per hour applied in 24 hr. The range of validity for these equations are for wastewater application rates between 0.21 and 0.84 cm/hr. Percent reduction of algae was 100 percent for application rates less than or equal to 0.21 cm/hr. Reduction efficiency decreased with increasing rates of application. It should also be noted that the variability associated with algae reduction increased at the higher rates of application.

Equation 1 was developed using data from a 2-percent slope. When the fit of the equation was compared with data taken from the 4- and 8-percent slopes (Figure 11), the points were within the range of the 2-percent data. Slope appeared to have no effect on algae removal as indicated by the general similarity of data obtained from each slope. Results indicated that for algae reduction of 90 percent or greater, wastewater application rates should be less than or equal to 0.42 cm/hr applied continuously in a 24 hr period, 7 days/week. Algae reduction on systems receiving lower rates of wastewater application should approach 100 percent. While these data were obtained for continuous wastewater application, similar results would be expected for intermittent application.

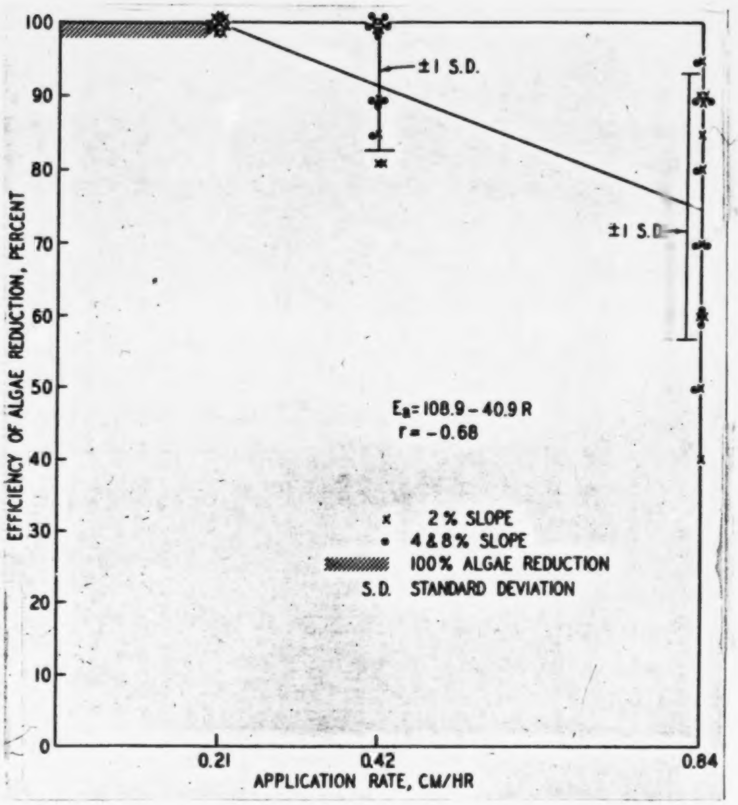

Figure 11. **Influence of application rate on reduction of algae from wastewater treated by overland flow.**

Stormwater Runoff

Rainfall data and calibration curves for Parshall flumes were used to develop the rainfall-runoff relationship and resulting regression equation shown in Figure 12. Only the rainfall occurring after a normal irrigation cycle was used to develop the relationship due to the difficulty of separating irrigation runoff from rainfall-induced runoff. The abscissa intercept for the calculated regression equation is 4.12, indicating high antecedent soil moisture, and runoff beginning after only 4.12 mm of rainfall.

Assessment of stormwater runoff from overland flow systems must be done relative to requirements set forth in the discharge permit. Discharge permits commonly place limits on both concentration and mass discharge of the regulated constituents. Based on the data collected, concentrations of BOD_5 and TSS do not appear to be problematic primarily because of the dilution from increased flows. However, the mass loads generated through these increased flows can be a legitimate concern. Table 3 compares the percent discharge permit limits for Utica, Mississippi, with discharge characteristics for a storm with a recurrence interval of approximately 3 years. Average discharge concentrations are below the permit values for both BOD_5

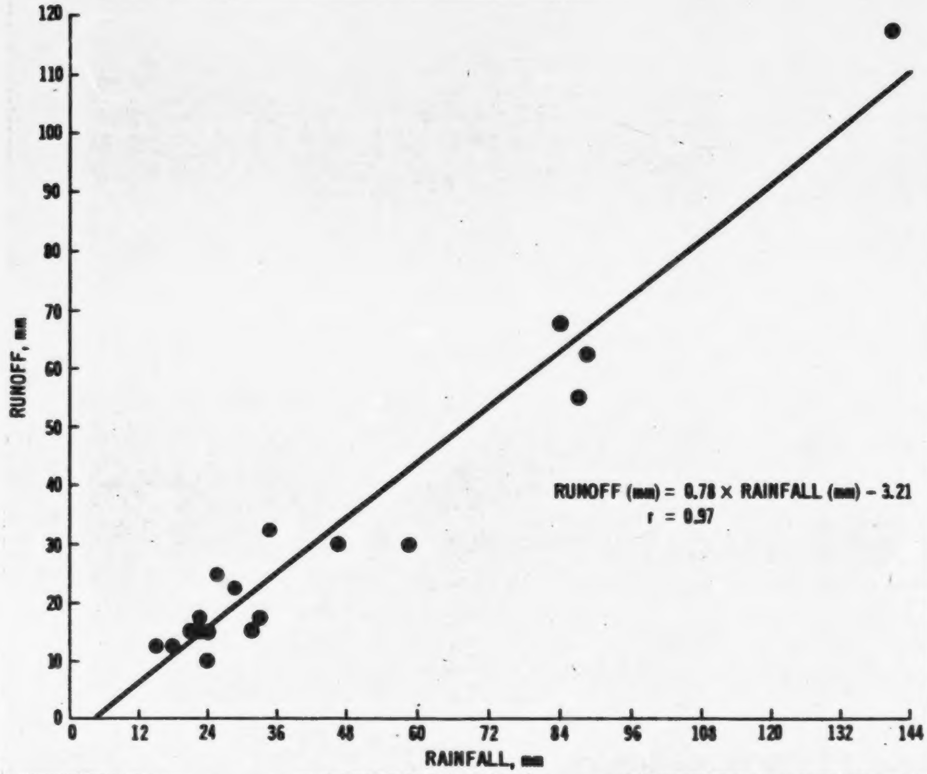

Figure 12. Rainfall-runoff relationship and resulting regression equation for an overland flow wastewater treatment system.

TABLE 3. COMPARISON OF STORM DISCHARGE VERSUS UTICA, MISSISSIPPI, PERMIT REQUIREMENTS FOR BIOCHEMICAL OXYGEN DEMAND AND TOTAL SUSPENDED SOLIDS

	Utica Permit		Typical Storm Discharge	
	Monthly Average	Weekly Average	Concentration mg/ℓ	Load, kg/day
BOD_5	60 mg/ℓ	90 mg/ℓ	25	
	41 kg/day	61 kg/day		98
TSS	180 mg/ℓ	180 mg/ℓ	20	
	123 kg/day	123 kg/day		83

Design flow = 681 m^3/day
(0.18 MGD)

and TSS. However, while the TSS load is under the permit limit, the load limit is exceeded for BOD5. Had the permit been written for what is commonly accepted as secondary treatment, i.e., 30 mg/ℓ for BOD5 and TSS, the permit would have been violated with respect to load for both constituents. It must be noted that when an overland flow system is operating at its design capacity for both discharge and concentration, anything in excess of this, e.g., a storm event, will violate the discharge permit for that day. This does not imply, however, that stormwater runoff should be captured and recirculated for treatment. Such a practice would add substantial pumping costs and land requirements to the system. Under the climatic conditions existing at Utica, Mississippi, overland flow has the unique capacity to reduce the volume of applied wastewater leaving the system as runoff by up to 50 percent through evapotranspiration and some infiltration during the spring, summer, and fall. By virtue of this volume reduction and a coincidental concentration reduction, the mass load is reduced below permit limits on nonrainfall days. The increased loads from stormwater runoff may then be offset by the decreased loads on nonrainfall days to produce weekly and monthly averages below the permit value.

Assessment of overland flow system performance during periods of rainfall must be done relative to discharge permit requirements. As shown in Table 4, the proposed TKN concentration and mass discharge limits for Utica, Mississippi, are contrasted with two storm events. The 21 November storm had a magnitude of 52 mm occurring in 4 hr during a normal irrigation cycle, and the 29 November storm had a magnitude of 86 mm occurring in 6.5 hr after the normal irrigation was completed. The former storm occurred during a normal irrigation cycle, whereas the latter occurred after the day's irrigation was completed. Consequently the total mass load for the 29 November storm is the sum of the storm load of 11.3 kg and a daily irrigation load of 2.1 kg. The average concentration for both storms is well below the permit value, but both of these storms violate the daily mass discharge limit. Due to the inherent ability of overland flow to reduce loads through runoff volume reduction on nonrainfall days, the average daily load computed for the entire month should in most cases be within permit limits. Figures 13 and 14 show TKN and total phosphorus loads discharged from the Utica overland flow system with the associated runoff. These curves may be used with a rainfall-runoff relationship to estimate the probability that a permit limit may be violated due to stormwater loads. The procedure to be followed is described below:

TABLE 4. COMPARISON OF STORM DISCHARGE VERSUS UTICA, MISSISSIPPI, PERMIT REQUIREMENTS FOR NITROGEN

Utica Permit TKN			Typical Storm Discharge	
Monthly Average	Weekly Average		21 Nov 77	29 Nov 77
5 mg/ℓ	7.5 mg/ℓ	Avg TKN conc, mg/ℓ	3.3	3.6
3 kg/day	5 kg/day	TKN load, kg	6.1	11.3
		Total load	6.1	13.4
		Recurrence interval	1 yr	3 yr
Design Flow = 681 m3/day (0.18 MGD)				

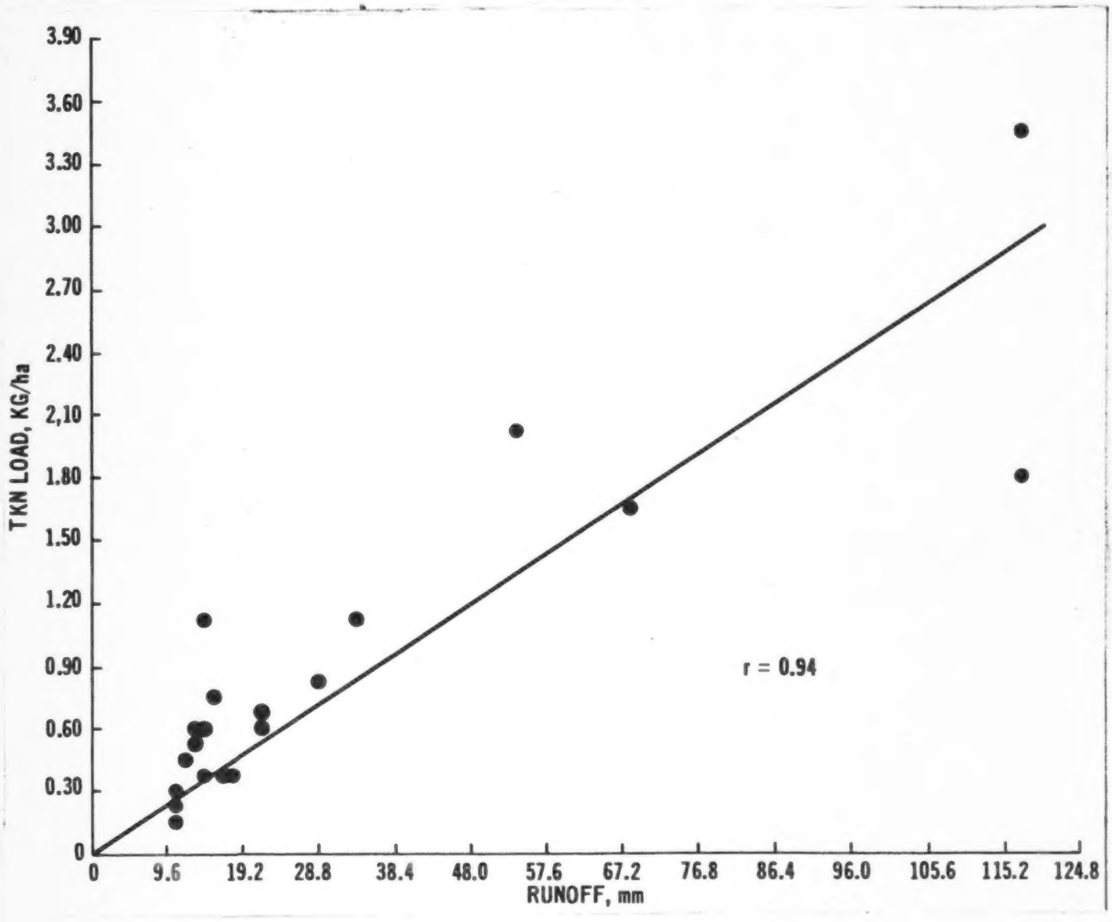

Figure 13. TKN load-runoff relationship for a prototype overload flow system during periods of rainfall.

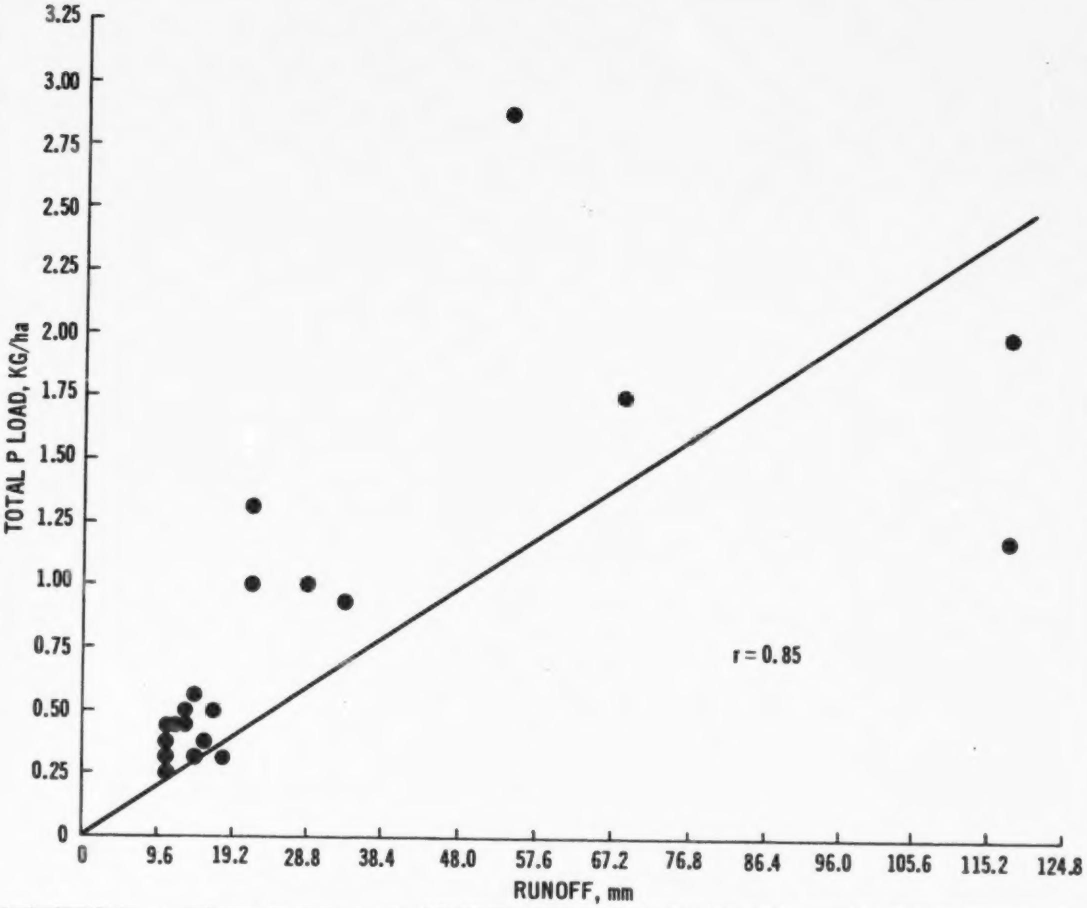

Figure 14. Total phosphorus load-runoff relationship for a prototype overland flow system during periods of rainfall.

Recommendations for Stormwater Runoff Management from Overland Flow Systems

There are certain options open to the planner/designer concerned with management of storm runoff from overland flow systems. These range from a requirement of no discharge to allowing full discharge with the storm runoff not being accountable to the discharge permit. The latter case is presently used in the State of Mississippi. When no discharge is allowed the design problem is reduced to providing pumping and conveyance facilities to return the excess flow to the lagoon or holding pond for reapplication. In this case additional land area must be provided to handle the normal wastewater flow plus storm runoff.

The most probable situation will be such that discharge of storm runoff is allowed but required to stay within the limits of concentration and mass loading for certain specified constituents. A recommended procedure for storm runoff management in such cases follows:

Step (1): Examine the discharge permit and determine the average daily concentration and mass load allowable for each regulated constituent. The product of the number of days per month and average allowable daily load will give the maximum allowable load for the month.

Step (2): Determine from the system design what the expected average daily discharge will be for both concentration and load. Determine the total load expected for the month. This involves making an accurate estimate of evapotranspiration and infiltration for the locale being considered to determine total monthly runoff volume and combining this value with the expected runoff concentration for a particular constituent. The difference between the permit value and expected value of load is the amount that can be allowed to discharge via storm runoff.

Step (3): From step 2 calculate the amount of rainfall required to produce the mass load that just brings the total discharge to the permit value. For nutrients, Figures 13 and 14 may be used to determine the runoff that will produce the required load, and a rainfall runoff relationship similar to Figure 12 but developed for local conditions may be used to determine the rainfall that will produce the subject runoff. By hydrologic frequency analysis (16) or referral to manuals such as that prepared by McWharter (17), determine probability that this amount of rainfall will be equalled or exceeded. Depending upon the locality and climate of the overland flow site, recycling and storage of storm runoff may not be required or may be required only during certain months.

Step (4): Using the analysis from step 3, consultations should be held with State regulatory officials to determine what probability is an acceptable risk before storm runoff collection and recycling are required.

Additional Considerations

The foregoing recommendations are based on data obtained from an overland flow system on a 2-percent slope. However, under normal operating conditions with no rainfall, similar runoff water quality was observed on both 2- and 8-percent slopes. Therefore, during periods of rainfall, similar runoff water quality would be anticipated from slopes of 2 to 8 percent.

Crop Management

Grass yield from the 8-percent slope was slightly greater than yield from the 2-percent slope (Table 5). Similarly, yield was significantly higher for the 2.54 cm, 18 hr, 5 day application than for the 1.27 cm, 6 hr, 5 day application.

In 1978, wastewater was applied continuously to two plots each on the 2- and 8-percent slopes, and the results are shown in Table 6. The analyses represent data for just one year whereas Table 5 represents two years data for only two depths of wastewater application. Similar results were evident in that both slope and application were significant. It is significant to note that the application of wastewater continuously did not appear to adversely affect yield. Application of 5.08 cm wastewater in 18 hr, 5 days/week during this same time period but on the 4-percent slope produced an average yield of 3.28 mton/ha/harvest and a total for the year of 13.13 mton/ha. Average annual yields ranging from 10.77 mton/ha (Table 5) to 13.84 mton/ha (Table 6) compared favorably with 11 mton/ha obtained by Larson (18) on better agricultural soils.

TABLE 5. GRASS YIELD FROM A PROTOTYPE OVERLAND FLOW LAND TREATMENT SYSTEM FOR TWO DEPTHS OF WASTEWATER APPLICATION AND SLOPES OF 2 AND 8 PERCENT

	Yield mton/ha/harvest*			
	Slope			
Wastewater Application	2 percent	8 percent	Treatment Mean	Total for Year, mton
1.27 cm, 6 hr, 5 day	2.66	2.71	2.69 a	10.77 a
2.54 cm, 18 hr, 5 day	2.66	3.24	2.95 b	11.83 b
Slope Mean	2.66 c†	2.98 d		

* Plots harvested four times/year, 1977 and 1978.

† Means in a given column or row followed by the same letter are not significantly different (p = 0.05).

TABLE 6. GRASS YIELD FROM A PROTOTYPE OVERLAND FLOW LAND TREATMENT SYSTEM FOR THREE WASTEWATER APPLICATIONS

	Yield mton/ha/harvest*			
	Slope			
Wastewater Application	2 percent	8 percent	Treatment Mean	Total for Year, mton
1.27 cm, 6 hr, 5 day	2.79	2.96	2.87 b	11.48 b
2.54 cm, 18 hr, 5 day	2.76	3.82	3.29 a	13.16 a
2.54 cm, 24 hr, 7 day	3.31	3.62	3.46 a	13.84 a
Slope Mean	2.95 c†	3.47 d		

* Plots harvested four times/year, 1978.

† Means in a given column or row followed by the same letter are not significantly different (p = 0.05).

Heavy Metals

Toxic heavy metal removal by overland flow has been shown to be very good. The distribution of Cd on the overland flow treatment area is shown in Table 7. The rather high removal of metal is attributed to the soil surface organic mat (biomass) where most of the heavy metals in particular are bound. This is not surprising since heavy metals are known to be very reactive with organic matter in agronomic soils. The majority of the applied metals accumulated in the biomass on the soil surface and closer to the point of wastewater application. Likewise, grass closest to the point of wastewater application contained elevated amounts of metals.

Coliforms

Removal of fecal coliforms from applied wastewater has been shown to be very effective when wastewater was applied slowly at rates of 0.10 cm/hr or less for extended periods of 18 and 24 hr (19). This more continuous application mode appeared to foster the development of an organic slime layer on the soil surface which appeared to entrap applied fecal coliforms and promote an active population of fecal coliform predators. Consequently, fecal coliform counts of less than 200 specific plate count (SPC)/100 ml were observed in the runoff (Figure 15). In contrast, shorter intermittent applications of 0.21 cm/hr for 6 hr resulted in fecal coliform counts in excess of 200/100 ml and sometimes greater than 2000/100 ml. These high counts were related to regrowth of fecal coliforms on the overland flow treatment surface and interference by false positive soil-borne bacteria.

TABLE 7. SUMMARY OF DISTRIBUTION OF CADMIUM ON THE OVERLAND FLOW SYSTEM AT UTICA, MISSISSIPPI

Component	Slope Distance, m						
	0		15		30		45
Water, mg/ℓ	0.0768 a*		0.0276 b		0.0065 c		0.0020 c
Grass, µg/g		6.76 a		2.65 b		0.45 c	
Soil, µg/g							
Biomass		307.6 a		113.5 b		25.4 c	
0-2.5 cm		3.2 d		1.4 d		0.5 d	
2.5-15 cm		0.7 d		0.5 d		0.4 d	

* Means followed by different letters within each component are significantly different at $p = 0.05$.

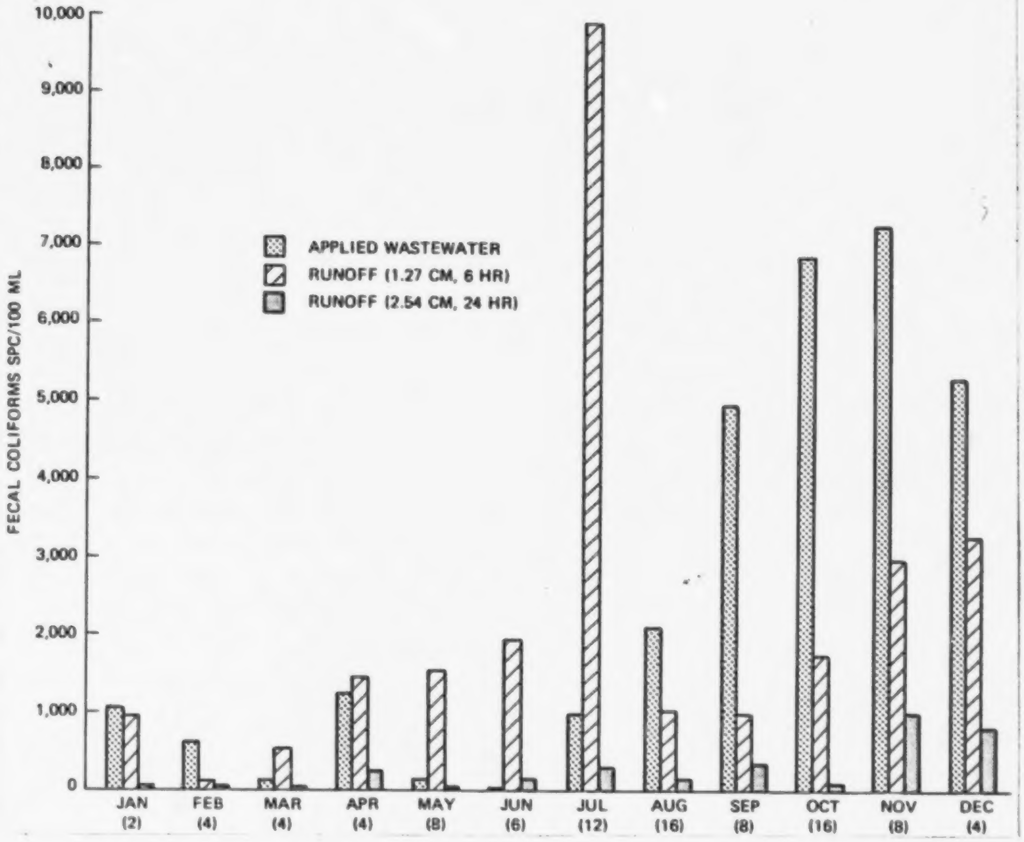

Figure 15. Fecal coliform counts in Utica overland flow plot samples. Replicate numbers are given in parentheses (Reference 19).

RECOMMENDATIONS

Based on experience gained and results obtained from operation of a prototype overland flow facility over approximately 4 years, the following recommendations are made for overland flow operation when using similar wastewater in similar climates. Selection of a wastewater application schedule involves knowing amount or depth, period per application, and number of days per week. In general, for climate conditions similar to those found in the Southeast, overland flow will provide excellent treatment for BOD_5, TSS, nitrogen, and heavy metals year-round. Specific recommendations for treatment of particular parameters follow.

BOD_5 and TSS

A year-round average of 80-85 percent mass reduction, and runoff concentration less than 10 mg/ℓ may be expected when wastewater is applied in the amount of 2.54 cm, 18 or 24 hr/day, 5 or 7 days/week. These results are for applied wastewater concentrations of 20-30 mg/ℓ. However, a continuous summer application of 10.16 cm/day of a wastewater containing 60 and 90 mg/ℓ of BOD_5 and TSS resulted in reduction efficiencies greater than 80 percent and runoff concentrations less than 15 mg/ℓ for both constituents.

Nitrogen

For 80-percent reduction of TKN and runoff concentrations ≤5 mg/ℓ, wastewater should be applied for most of the year at 2.54 cm in 18 or 24 hr, 5 or 7 days/week. Since the continuous application period did not adversely affect TKN reduction, this mode of operation would allow an approximate additional 5 cm of wastewater/week to be applied. During the winter, application should be decreased to 1.27 cm applied in 18 hr, 7 days/week. This application resulted in reduction of TKN as high as 90 percent in the winter and runoff concentrations as low as 2 mg/ℓ. Year-round TKN reduction and runoff concentrations of 88 percent and less than 4 mg/ℓ may be expected on the average with this reduced application.

Ammonium reduction will average 95 percent or greater year round with runoff concentrations below 2 mg/ℓ at wastewater applications up to 5.08 cm applied in 18 hr, 5 days/week. Since continuous application did not affect ammonium reduction at lower applications, it is believed that reduction will be maintained for continuous application even at the 5.08-cm depth. Ammonium reduction may be expected to drop to 85 percent with runoff concentrations about 3 mg/ℓ during the winter. If the application is reduced to 1.27 cm, 18 hr, 7 days/week during the winter, reduction efficiency will increase to about 98 percent.

Concentrations of nitrate-N will be maintained at <5 mg/ℓ for all applications up to and including 5.08 cm wastewater applied in 18 hours daily, 5 days/week, except for the winter. Nitrate concentrations will increase for all applications during the winter. To maintain runoff concentrations of NO_3^--N less than 5 mg/ℓ during the winter, the application of wastewater should be decreased to 1.27 cm applied in 18 hr, 7 days/week.

Phosphorus

Overland flow is, in general, not suited for phosphorus reduction. Best results for phosphorus reduction without chemical flocculation may be obtained by applying 1.27 cm wastewater in 18 hr, 5 days/week which should result in an average year-round reduction of 68 percent and total P runoff concentrations ≤5 mg/ℓ. Reduction efficiencies as high as 90 percent and runoff total P concentrations as low as 1-2 mg/ℓ may be obtained with addition of aluminum sulfate as a flocculating agent to the applied wastewater. The resultant sludge accumulation on the treatment slope was not found to be detrimental to the vegetation during this study.

Heavy metals

For wastewater applications up to 2.54 cm, 18 hr, 5 days/week removal efficiencies of cadmium, copper, nickel, and zinc may be expected to average approximately 91, 87, 82, and 87 percent, respectively. Even though overland flow can remove metals from applied wastewater, metal concentrations lower than those used in Utica should be applied. Lower applied metal concentrations will result in slower accumulation of metals on the overland flow system.

Fecal coliforms

Reduction of fecal coliform to 200 SPC/100 ml may be achieved through continuous wastewater application of 2.54 cm/day. The critical factor is the continuous application. Reduction to these levels is, however, sporadic in that it is not achieved year round (Figure 15).

Crop Management

Harvesting grass three times per year rather than four produced approximately the same yield of grass. Since harvesting requires a period of drying followed by additional time requirements for cutting, baling, and/or grass removal, less frequent harvesting reduces storage requirements and cuts operation and maintenance costs. There is some indication at Utica, Mississippi, and in Birmingham, England that grass removal could be reduced to once per year without adverse effect upon wastewater treatment. This management scheme would reduce the amount of downtime for the wastewater treatment system. There is insufficient data at this time to recommend the elimination of grass removal on overland flow systems.

Winter overseeding of ryegrass to improve wastewater renovation is not recommended. This practice does not improve water quality nor does it affect yield.

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Question (by Mr. Ray Shull, Texas Department of Water Resources, Austin, TX): I believe you said that after a period of time you had basically a native grass stand growing in the area of application?

Response (by Mr. Peters): This was true to a certain extent. Reed canary grass was the predominant grass of those originally planted. Native grasses such as barnyard grass, Dallis grass and nutgrass became established on the treatment area. These grasses took up nitrogen and phosphorus and consequently we did not see any decrease in treatment because of their presence. Reseeding the treatment area with reed canary grass reduced the encroachment and growth of these native grasses.

PB82-194325

Municipal Wastewater Treatment by Overland Flow at Pauls Valley, Oklahoma

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INTRODUCTION

The literature reveals a long-standing interest but a relatively low level of utilization of land application of municipal and industrial wastewater in the United States prior to 1972 (1). The passage of PL 92-500 stimulated a revival of interest in land application and the innovative and alternative provisions of PL 95-217 virtually assure an increasing level of utilization (2) not only for wastewater treatment and disposal but also for resource recovery and the production of food and fiber. Unfortunately, the accumulated design and performance data are limited and mostly empirical, especially in the area of overland flow.

Of the estimated 3,410 land treatment systems in the United States (1), most have involved wastewaters, climates, terrains, and soil types amenable to rapid infiltration or irrigation (slow rate infiltration) and relatively few have involved sloped impervious soils where overland flow would be required. Of the comparatively few overland flow systems in the United States, the majority have been designed to receive food processing wastes while only one facility constructed to treat raw municipal wastewater has been extensively studied and prominently reported (3). Based on this, it is apparent that overland flow must be further subjected to comprehensive application and evaluation if innovative and alternative treatment by land application is to be extended to the agriculturally marginal soils and terrains that characterize many areas in the United States.

The primary objectives of this study were to assess, on a seasonal basis, (a) the treatment of raw (screened) municipal wastewater by rotating boom, fixed riser, and trough methods of application on overland flow modules constructed on 2- and 3-percent slopes, (b) the treatment of wastewater stabilization pond effluent by the trough and riser methods of application on similarly constructed plots, and (c) the treatment achieved by overland flow compared to a wastewater stabilization pond receiving the same raw municipal wastewater.

Other objectives of this investigation were to determine and compare (a) the bacterial and viral components of the wastewater before and after application to the overland flow plots, (b) the airborne microorganisms upwind and downwind of the rotating boom applicators, and (c) the chemical composition of the soil before initiation and after termination of wastewater application.

RESEARCH FACILITIES

Pauls Valley is a predominantly agricultural community with a population of approximately 6,000 located in the Washita River basin in Garvin County in Central Oklahoma. Climatic conditions produce a mean annual rainfall of 34.8 inches (88.4cm), a mean lake evaporation of 58.5 inches (148.6cm), an average high temperature of 75.1^{o}F (23.9^{o}C), and an average low temperature of 44.9^{o}F (9.9^{o}C) (4). With a first killing frost in early November and a last killing frost in early April, the average annual growing season is 214 days. The City of Pauls Valley generates about 0.7 MGD (30.7 l/s) of municipal wastewater which is treated in a four-celled wastewater stabilization pond having a total surface area of approximately 33 acres (13 ha).

The study site, as shown in Figure 1, was located adjacent to the wastewater stabilization pond and consisted of a total of 8 acres (3.2 ha) the upper half of which was graded to a 3-percent slope while the lower half had a finished grade of 2 percent. Most of the soil at the site was of the

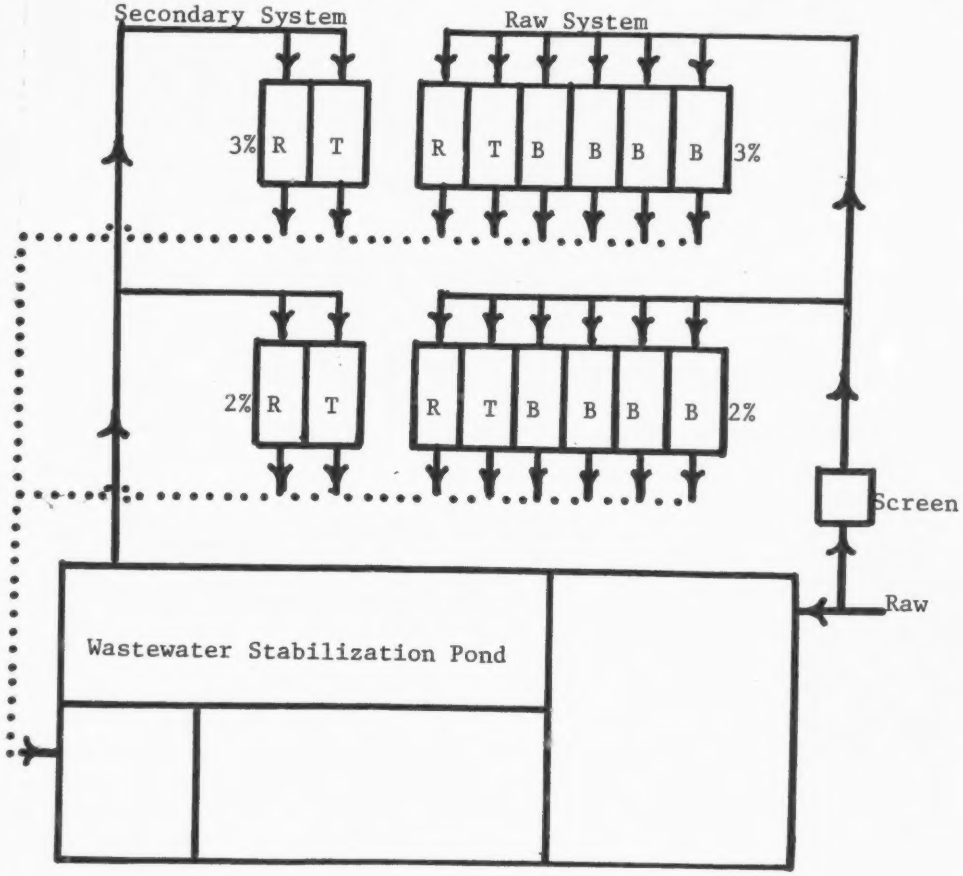

Figure 1. Diagram of research facilities.

Renfrow series which has a percolation rate of less than 0.06 inches/hour (1.5 mm/hour) for the 13-inch (33-cm) depth and below. Three acres (1.2 ha) on each slope were assigned to treat raw wastewater and were subdivided into six modules each containing two plots 65 feet (20m) wide by 165 feet (50m) long. Four of the raw system modules (8 plots) on each slope were designated to receive raw wastewater by the boom method while one module (2 plots) was equipped with troughs and the remaining module (2 plots) on each slope was designed with riser applicators.

The remaining 2 acres (0.8 ha) were designated as the secondary treatment system and were subdivided into two modules on each slope. Each module contained two plots of the same dimensions employed in the raw system. One module on each slope was assigned to the trough applicators while the remaining module on each slope was equipped with risers.

Each module was drained by a channel at the lower end of the slope, which conveyed the effluent flow to a centrally located v-notch weir. Barrier terraces were constructed between each subdivision to maintain independent flow across the plots for each application method.

All plots were seeded with a combination of warm and cool weather grasses: Kentucky-31 fescue at 30 pounds/acre (35 kg/ha), annual rye grass at 15 pounds/acre (17 kg/ha) and bermuda at 6 pounds/acre (7 kg/ha). Reseeding to replace the annual rye was required each fall.

Approximately 0.14 MGD (6.1 l/s) of wastewater screened through a stainless steel wire cloth with 1/4-inch (0.6-cm) openings was applied to the 6 acres (2.4 ha) assigned to the raw treatment system and 0.07 MGD (3.1 l/s) of wastewater stabilization pond effluent was applied to the 2 acres (0.8 ha) designated as the secondary treatment system. The raw system operated 24 hours/day, 7 days/week with each plot receiving flow on an 8-hour-on 16-hour-off cycle. Each week the dosing period was rotated so that at the end of each 3-week cycle, each plot had been operated an equal amount of time in each of the three daily 8-hour intervals. The secondary system was operated on a 12-hour-on 12-hour-off daily cycle.

As presented in earlier reports (5,6), the rotating boom applicators which were employed only on the raw system were constructed of two 25-foot (7.6-m) sections of 1-inch (2.5-cm) diameter pipe with each arm equipped with a 3/16-inch (0.48-cm) 180° fan nozzle. The trough method of application utilized on both the raw and secondary systems, consisted of a 6-inch (15-cm) diameter PVC pipe laid at ground level across the upper end of the plot. Wastewater was distributed through 3/4-inch (1.9-cm) horizontal trickling orifices placed on 3-foot (0.9-m) centers. Application of both raw wastewater and stabilization pond effluent utilizing fixed risers was accomplished by placing 3 1/2-foot (1.1-m) high solid-set risers at 8-foot (2.4-m) intervals across the upper end of the slope. Each riser was elbowed downward and fitted with the same size and type nozzle employed on the rotating booms.

METHODS

During each 3-week interval of operation, influent and sequential effluent wastewater samples were collected three times per week for both the raw and secondary systems. The plot effluent samples were taken during the 8 a.m. to 4 p.m. shift approximately halfway through the 8-hour cycle on the raw system and the 12-hour cycle on the secondary system. Samples thus acquired were analyzed for BOD, COD, suspended solids (total nonfilterable residue), fecal coliform, total phosphorus, nitrate, ammonia, organic nitrogen, turbidity, pH, and dissolved solids (filterable residue) according to procedures outlined in Standard Methods (7) and EPA Manual of Methods (8). Data resulting from these analyses were tabulated by analytical parameter, method of application, and slope. These were then classified as raw or secondary systems and grouped according to summer or winter operation. Each analytical category in each of these four groups was described by calculation of arithmetic mean and standard deviation. Comparison of various effluent averages with their respective influent averages allowed calculation of treatment efficiencies achieved by the various application methods and slopes. Two-way analysis of variance (3 x 2 factorial for the raw system and 2 x 2 factorial for the secondary system) permitted further analysis of the analytical results (9). The experimental design allowed multiple range and t comparisons of the effluent concentrations from the various application methods of a given slope and/or a similar comparison for data from the two slopes for a given application method (9).

In order to determine the effects of overland flow treatment on the levels of enteric bacteria in the wastewater, influent and effluent total coliform and total bacterial colony counts were monitored biweekly for all application methods and slopes for the raw treatment system. Acquired samples were serially diluted and plated on two media: nutrient agar (NA) and eosin methylene blue agar (EMB). The plates were incubated at 95°F (35°C) for 18 to 24 hours at which time the NA counts were reported as total bacterial count (TBC) and the EMB counts were recorded as total coliform count (TCC). Influent and effluent samples for viral analyses were collected from both the raw and secondary systems on a monthly basis. The analysis consisted primarily of concentrating enteric viruses from the wastewater samples by the bentonite adsorption technique and assaying the samples for the quantity of viruses determined as plaque-forming units per liter (PFU/l). The techniques utilized were described in the original project report (6).

In addition to the wastewater analyses outlined above, surface and subsurface soil samples were taken from the test modules before application of the wastewater was initiated and again at the conclusion of the study. These samples were analyzed for calcium, copper, iron, magnesium, manganese, nickel, phosphorus, potassium, sodium, and zinc.

Air samples for total and coliform bacterial analysis were collected biweekly by placing Anderson drum samplers upwind and downwind of the rotating boom applicators on the 2-percent slope. Two samplers were placed at each sampling location, one containing NA for TBC analysis and the other containing EMB for TCC analysis. After a 1-hour period of operation, the cannisters were removed and analyzed as described for the bacteriological analysis of the wastewater samples. The ambient air was also monitored for total particle count and size distribution at the same frequency, locations, and sampling times described above by drawing a measured volume through a 37-mm, 0.45-micron cellulose acetate filter contained in a plastic cassette. Size-count distributions were determined microscopically at 400x utilizing a Porton Graticule and the Truncated Multiple Traverse procedure (ASTM D-2009-70). The method used for the monthly collection of air samples for viral analysis was similar to that employed for the bacteriological air samples except a liquid impinger containing 250 ml of a saline menstruum was substituted for the Anderson drum sampler. Acquired samples were concentrated and assayed as described for the wastewater viral samples.

RESULTS AND DISCUSSION

The first year of operation was utilized achieving plot stability, establishing the vegetative cover, installing hydraulic and structural modifications, and developing the sampling and analytical protocols. Data produced during this period were analyzed for control purposes, for monitoring maturation of the systems, and for developing baselines for the second year of operation presented in this report. These preliminary data also indicated that the regulatory parameters, BOD, suspended solids, and fecal coliform along with the nutrient parameters, total phosphorus, nitrate, ammonia, and organic nitrogen, were the most significant for describing and evaluating the performance of the systems as operated in this study.

Raw System. As shown in Table 1, a comparison of the influent with the various effluent BOD levels for winter operation of the raw system indicates treatment efficiencies which varied from 68 percent for the 2-percent riser to 82 percent for the 3-percent boom. These performance levels are somewhat lower than mechanical secondary treatment and may be attributed, at least in part, to winter temperatures and the relatively dilute nature of the raw wastewater. From the standpoint of effluent limitations, the corresponding BOD levels ranged from 42.1 to 24.0 mg/l with only the 3-percent boom being less than 30 mg/l. The analysis of variance (AOV) indicated that the slope of the plots rather than the method of application significantly influenced

Table 1. Raw system, winter application.

			Application Method					
			Riser		Trough		Boom	
Anal. Par.	Infl. Conc.	% Slope	Eff. Conc.	% Red.	Eff. Conc.	% Red.	Eff. Conc.	% Red.
BOD mg/l	130	3	37.7	71	39.1	70	24.0	82
		2	42.1	68	40.4	69	39.8	69
SS mg/l	90.7	3	15.6	83	11.0	88	12.1	87
		2	11.2	88	11.9	87	12.0	87
F. Coli 10^6/100ml	3.9	3	1.5	62	1.2	69	2.3	41
		2	1.3	67	1.0	74	2.4	38

the level of effluent BOD. In this case, the steeper slope produced lower levels; however, considering the absolute differences involved, the practical significance is limited.

The suspended solids data reveal a more favorable performance. Compared to an influent average of 90.7 mg/l, the various effluents ranged from 11.0 mg/l for the 3-percent trough to 15.6 mg/l for the 3-percent riser, all of which were well below the 30-mg/l level. The AOV indicated no statistical significance associated with either the slope or method of application. From the standpoint of treatment efficiency, all plots achieved reductions of 83 to 88 percent, levels which approach those anticipated for mechanical secondary treatment.

Of the normal regulatory parameters, fecal coliform analyses indicated the poorest performance. With influent and effluent concentrations all in the range of 10^6/100ml, all reductions were less than one order of magnitude and have little, if any, practical significance even though the effluent from both the 2 and 3 percent booms had statistically higher concentrations than did the troughs or risers.

The nutrient parameters reported in Table 2 reveal that the riser and trough application methods resulted in reductions of only 8 to 19 percent in total phosphorus. The effluent concentrations from the boom plots were statistically different and, in fact, demonstrated increases in phosphorus concentrations. Given the levels in the influent and various effluents, the relatively small changes produced by the plots have no practical significance other than to indicate that under the conditions tested, no meaningful changes in phosphorus concentrations were achieved.

Table 2. Raw system, winter application.

			Application Method					
Anal.			Riser		Trough		Boom	
Par. mg/l	Infl. Conc.	% Slope	Eff. Conc.	% Red.	Eff. Conc.	% Red.	Eff. Conc.	% Red.
Total P	8.46	3	7.55	11	6.87	19	9.55	-13
		2	7.64	10	7.75	8	9.64	-14
NO_3 N	0.04	3	0.24		0.21		0.74	
		2	0.19		0.26		0.44	
NH_3 N	16.5	3	6.89	58	8.47	49	11.4	31
		2	9.56	42	8.56	48	13.4	19
Org. N	7.28	3	3.47	52	3.65	50	2.66	63
		2	4.01	45	3.64	50	3.12	57

Examination of the nitrate data indicates that the riser and trough methods of application performed similarly in that the average nitrate-nitrogen concentrations ranged from 0.19 to 0.26 mg/l. Even though the levels were significantly higher for the boom plots, all levels were well below

1 mg/l, a comparatively low level for an aerobic biological treatment system even under winter conditions. The ammonia data illustrate a similar pattern. The riser and trough methods produced average ammonia-nitrogen concentrations ranging from 6.89 to 9.56 mg/l and corresponding reductions varying from 58 to 42 percent. The effluents from the two boom plots were significantly higher and resulted in reductions of only 19 and 31 percent. The organic nitrogen data present the corresponding view in that the boom applicators produced lower effluent concentrations (2.66 and 3.12 mg/l) and consequently higher reductions (63 and 57 percent) than did the trough or riser plots. In the latter case, effluent concentrations ranged from 3.47 to 4.01 mg/l with corresponding percentage reductions varying from 52 to 45. Given the relatively small range of effluent levels, no practical or statistical significance could be associated with either slope or any application method.

Overall, it would appear that on a concentration basis, about 50 percent of the organic nitrogen was removed by overland flow presumably by conversion to other nitrogen forms. Similarly, the concentration of ammonia-nitrogen was reduced by almost half by loss to the atmosphere and/or by conversion to nitrate which would then be subject to discharge, plant uptake, and/or anaerobic denitrification in the soil. Since the concentration of nitrate in the effluent was nominal, and since under the soil and temperature conditions encountered plant uptake of nitrate and anaerobic denitrification in the soil should be minimal, it would appear that nitrification was essentially blocked. Thus, it is indicated that under these experimental conditions, the loss of nitrogen was limited and attributable to changes in organic nitrogen forms and volatilization of ammonia.

As may be seen in Table 3, which illustrates the performance of the raw system during summer operations, the effluent BOD averages for the various plots ranged from 8.3 mg/l for the 2-percent boom to 21.0 mg/l for the 3-percent trough. The AOV indicated that the boom plots produced a significantly lower effluent BOD with no differences attributable to slope. Since all effluent concentrations were less than 30 mg/l, all methods tested demonstrated the ability to meet common BOD effluent limits during the extended summer operational period. Even though the influent BOD dropped to 117 mg/l,

Table 3. Raw system, summer application.

			Application Method					
			Riser		Trough		Boom	
Anal. Par.	Infl. Conc.	% Slope	Eff. Conc.	% Red.	Eff. Conc.	% Red.	Eff. Conc.	% Red.
BOD mg/l	117	3	14.2	88	21.0	82	8.6	93
		2	18.2	84	18.3	84	8.3	93
SS mg/l	105	3	9.4	91	10.6	90	3.6	97
		2	6.4	94	6.6	94	3.6	97
F. Coli 10^6/100ml	5	3	1.4	72	1.8	64	1.2	76
		2	1.2	76	1.2	76	0.49	90

the treatment efficiencies ranged from 82 to 93 percent and compare favorably with the anticipated performance of mechanical secondary treatment alternatives.

The suspended solids data also indicate an improved performance compared to the winter operation. Effluent levels ranged from 3.6 to 10.6 mg/l and even though statistically significantly lower levels were indicated for both the 2-percent slope and the boom method of application, the absolute differences are of little, if any, practical significance. All effluent levels were well below 30 mg/l and treatment efficiencies were at or above 90 percent, which compares well with mechanical secondary treatment.

The fecal coliform data do not conform to the above pattern. Similar to the observations made during the winter operation, influent and effluent levels alike were in the range or 10^6/100 ml. Even though the percentage reductions show an increase compared to the winter operation and even though statistical significance was indicated for the 2-percent slope, these observations have little practical meaning in view of the overall effluent levels.

The phosphorus data in Table 4 indicate very little variation among the effluent concentrations from the various plots and very little variation between these levels and those observed for the winter operation. The principal difference is that for the summer operation all but one plot demonstrated an increase in phosphorus concentration. This indicates that under the conditions of this study, the plots achieved little, if any, phosphorus removal from the wastewater even during the growing season.

Table 4. Raw system, summer application.

			Application Method					
			Riser		Trough		Boom	
Anal. Par. mg/l	Infl. Conc.	% Slope	Eff. Conc.	% Red.	Eff. Conc.	% Red.	Eff. Conc.	% Red.
Total P	8.3	3	7.9	5	8.5	-2	9.2	-11
		2	8.7	-5	8.9	-7	9.2	-11
NO_3 N	0.05	3	0.18		0.16		1.04	
		2	0.18		0.24		0.67	
NH_3 N	16.7	3	4.2	75	7.4	56	3.1	81
		2	6.9	59	6.9	59	3.4	80
Org. N	8.5	3	4.0	53	4.8	44	2.9	66
		2	4.6	46	5.0	41	3.1	64

The nitrate-nitrogen data reveal a pattern similar to that observed for the winter operation in that the effluents from all plots, especially the riser and trough plots, contained relatively low levels of nitrate. Even though the boom plots, especially the ones on the 3-percent slope, showed statistically higher effluent concentrations, all average nitrate-nitrogen levels were 1 mg/1 or less, which leads to the same general observation concerning nitrification that was made for the winter operation.

Comparison of the effluent ammonia levels indicates a range of 3.1 mg/l for the 3-percent boom to 7.4 mg/l for the 3-percent trough with statistically lower levels being associated with the boom applicators and to a lesser extent with the 3-percent slope. The corresponding treatment efficiencies ranged from 81 to 56 percent. The lower effluent levels and the resulting higher treatment efficiencies compared to the winter operation, indicate the benefit of higher ambient temperatures and suggest volatilization as the major ammonia removal mechanism.

The organic nitrogen data present a pattern of effluent concentrations and treatment efficiencies almost identical to those observed for the winter operation. The major difference is in the statistical significance associated with the 3-percent slope in general, and with the boom method in particular. Considering the range of values observed, this has little practical interpretation and leads to the conclusion that the higher ambient temperatures of summer had no apparent benefit in the reduction of organic nitrogen levels.

Overall, the nitrogen balance for both summer and winter operations appears to have been similar for nitrate and organic nitrogen levels; however, the increased loss of ammonia during the warmer temperatures resulted in a much higher loss of total nitrogen for the summer operation.

Table 5. Secondary system, winter application.

			Application Method			
			Riser		Trough	
Anal. Par.	Infl. Conc.	% Slope	Eff. Conc.	% Red.	Eff. Conc.	% Red.
BOD mg/1	16.2	3	13.8	15	17.2	-6
		2	9.30	43	9.40	42
SS mg/1	26.1	3	15.7	40	19.9	24
		2	6.67	74	6.33	76
F. Coli 10^4/100ml	6.0	3	4.5	25	6.4	-7
		2	2.5	58	1.8	70

Secondary System. Inspection of the data in Table 5 reveals that for the secondary system operated under winter conditions, the effluent BOD levels were well below 30 mg/1, with those from the 2-percent slope being statistically lower than those from the 3-percent slope. Since the influent (stabilization pond effluent) was also below 30 mg/1 in BOD the corresponding percentage reductions were comparatively low. Thus, the benefits of winter operation, at least from the standpoint of BOD reduction of a secondary effluent, appear to be nominal. These data do, however, indicate that winter operation as opposed to winter storage can be realized especially if effluent BOD limits of less than 10 mg/1 and/or controlled discharge are required.

The suspended solids data lead to the same general observation, that is, all effluent levels were well below 30 mg/l with the 2-percent plots having significantly lower levels than those from the 3-percent plots. Even though the influent level was below 30 mg/l, the treatment efficiencies on the 2-percent slope were relatively high and indicate that effluent levels below 10 mg/l can be produced under winter conditions.

Similar to the raw system, the fecal coliform reductions were less than one order of magnitude and again emphasize that overland flow as operated in this study could not achieve effluent fecal coliform levels in the range of 10^2/100 ml.

The nutrient parameters outlined in Table 6 reveal that like the raw system, the secondary system produced comparatively uniform effluent levels of phosphorus. The low removal efficiencies demonstrate little uptake under the test conditions employed. The AOV indicates that the effluents from the riser plots were significantly higher in nitrate levels than were the effluents from the trough plots. Likewise, the flows from the 2-percent plots were statistically higher in nitrate than were those from the 3-percent plots; however, considering that all effluent levels were below 1 mg/l, an overall low level of nitrification is indicated and the relatively small differences appear to have limited meaning. This was consistent with the finding for the raw system even though the influents to the two systems were markedly dissimilar. The ammonia and organic nitrogen levels exhibited the same general pattern for the secondary system as was seen for the raw system in that the effluent concentrations for the winter operation were relatively consistent between the application methods and slopes. The lower percentage reductions for the secondary system are understandable in view of the differences in nature of the two influents especially with regard to the organic nitrogen.

Table 6. Secondary system, winter application.

			Application Method			
			Riser		Trough	
Anal. Par. mg/l	Infl. Conc.	% Slope	Eff. Conc.	% Red.	Eff. Conc.	% Red.
Total P	12.1	3	10.4	14	10.9	10
		2	10.7	12	10.1	17
NO_3 N	0.06	3	0.57		0.15	
		2	0.94		0.60	
NH_3 N	13.5	3	8.41	38	10.8	20
		2	11.0	19	9.28	31
Org. N	3.93	3	2.81	28	4.04	-3
		2	2.42	38	2.24	43

Overall, the nitrogen balance for the winter operation indicates that influent levels were comparatively high in ammonia and low in organic nitrogen with a relatively small change of 24 percent of the total nitrogen being removed by the applied treatment.

As may be seen in Table 7, the summer effluent BOD levels ranged from 18.6 mg/l for the 2-percent trough to 25 mg/l for the 3-percent trough with no statistical inference associated with either the method of application or the slope. The percentage reductions, which ranged from 33 to 10 percent, indicate that the influent BOD which is primarily in the form of algal protein, is not readily decomposed under the overland flow conditions tested. The effluent suspended solids levels varied from 60.9 to 101 mg/l with the risers producing significantly lower levels than did the troughs; however, the practical significance of this is lessened by the fact that all effluent levels were well above 30 mg/l. A comparison to the suspended solids levels from the raw system for the summer operation suggests that the type of suspended solids rather than application method or slope is the principal influence on removal mechanism and, therefore, removal efficiency. The fecal coliform analyses for the summer operation indicated reductions of 42 to 52 percent for the plots on the 2-percent slope to increases of approximately 200 percent for the plots on the 3-percent slope. Although the differences are comparatively large, the influent as well as all effluent levels were in the 10^4 to 10^5/100ml range and the practical interpretation is consistent with previous coliform results for both the raw and secondary systems. Specifically, overland flow, at least as operated in this study, was relatively ineffective in reducing fecal coliform concentrations.

Table 7. Secondary system, summer application.

			Application Method			
			Riser		Trough	
Anal. Par.	Infl. Conc.	% Slope	Eff. Conc.	% Red.	Eff. Conc.	% Red.
BOD mg/l	27.7	3	18.7	32	25.0	10
		2	19.8	29	18.6	33
SS mg/l	114	3	60.9	47	101	11
		2	63.0	45	66.3	42
F. Coli 10^4/100ml	3.3	3	9.3	-182	10.0	-203
		2	1.6	52	1.9	42

The results of the total phosphorus analyses presented in Table 8 varied from 4.21 to 5.87 mg/l which are lower values than were observed for the winter operation; however, the summer influent levels were also lower. Consequently, the overall performances were comparable in that the reductions in the concentration of total phosphorus were relatively small. The plots on the 3-percent slope produced statistically lower effluent levels; however, the maximum difference between plots was less than 2 mg/l, and the practical significance of this finding is limited. Even though the reductions achieved by the secondary system were somewhat low, they were higher and more consistent than those from the raw system for both summer and winter operation.

Examination of the nitrate levels reveals a picture similar to that observed for the winter operation in that the influent level averaged less

Table 8. Secondary system, summer application.

Anal. Par. mg/l	Infl. Conc.	% Slope	Application Method: Riser Eff. Conc.	Riser % Red.	Trough Eff. Conc.	Trough % Red.
Total P	6.31	3	4.21	33	4.62	27
		2	5.87	7	5.60	11
NO_3 N	0.08	3	0.10		0.13	
		2	0.29		0.17	
NH_3 N	1.70	3	0.21	88	0.27	84
		2	0.48	72	0.44	74
Org N	13.8	3	10.5	24	14.0	-1
		2	9.1	34	9.4	32

than 0.1 mg/l and the effluent means were less than 0.3 mg/l. The indicated degree of nitrification is small, which is consistent for the winter operation of this system as well as for both seasonal operations of the raw system. On the other hand, the effluent ammonia-nitrogen levels averaged below 0.5 mg/l compared to the winter operation where the levels ranged from 8.41 to 11.0 mg/l. The summer removal efficiencies varied from 72 to 88 percent with both values observed on the riser plots. The apparent improvement in performance between summer and winter can be attributed, at least in part, to the warmer temperatures and lower influent levels for the summer operation. Statistically lower effluent levels were indicated for the 2-percent slope; however, the practicality of this finding is negated by the relatively small range encountered. The organic nitrogen data indicate a comparatively high influent level with little, if any, reduction on the various plots. Statistical significance was indicated for both method of application and slope; however, the relatively small range of values again minimizes practical interpretation.

Overall, the nitrogen balance for the summer operation reveals comparatively high influent levels of organic nitrogen, presumably in the form of algal protein, and relatively low levels of ammonia. Even though this was reversed for the winter, the overall change of 28 percent in the summer levels of total nitrogen was approximately the same as observed for the winter. These findings are consistent with the principal nitrogen loss mechanisms observed in this study to be conversion of organic nitrogen and ammonia volatilization. The major difference between the performance of the raw and secondary systems appears to be the nature of the influent organic nitrogen compounds and the mechanisms whereby the applied treatment could remove and decompose them.

Comparison With WSP. As may be seen in Table 9, the pond had an average BOD of 16.2 mg/l for the winter operation. This was not only well below the usual effluent limit of 30 mg/l but also well below the levels produced by all six plots, five of which were near or in excess of 40 mg/l. The percentage reduction averaged 87 percent for the pond compared to 71 percent for the plots. In contrast, the pond under winter conditions did not reduce suspended solids as well as did the plots. While all effluents were below 30 mg/l, the

Table 9. Comparison of overland flow and wastewater stabilization pond, winter application.

Anal. Par.	Infl. Conc.	% Slope	Riser Eff. Conc.	Trough Eff. Conc.	Boom Eff. Conc.	WSP Eff. Conc.
BOD mg/l	130	3	37.7	39.1	24.0	16.2
		2	42.1	40.4	39.8	
SS mg/l	90.7	3	15.6	11.0	12.1	26.1
		2	11.2	11.9	12.0	
F. Coli 10^6/100ml	3.9	3	1.5	1.2	2.3	0.06
		2	1.3	1.0	2.4	

percentage reduction of 71 percent for the pond was appreciably lower than the 83 to 88 percent range demonstrated by the plots. The fecal coliform data indicate that the pond achieved an average reduction of 98 percent which was considerably better than the range of 38 to 74 percent for the plots. With effluent levels in the range of 10^6/100ml for the plots and 10^4/100ml for the pond, neither process compares favorably with a limit in the range of 10^2/100 ml.

The phosphorus data in Table 10 reveal that the pond, along with both boom plots, produced average effluent concentrations higher than the influent. Even for the riser and trough plots where concentration reductions were noted, the percentage removals were low. It appears, therefore, that under winter conditions, neither the pond nor the plots were effective in removing phosphorus from raw wastewater. The nitrogen data gathered under winter conditions indicate that the nitrate levels in the pond effluent were virtually unchanged from the influent and were much lower than the plot effluents. However, since all effluents were below 1 mg/l, the difference between the plots and the

Table 10. Comparison of overland flow and wastewater stabilization pond, winter application.

Anal. Par. mg/l	Infl. Conc.	% Slope	Riser Eff. Conc.	Trough Eff. Conc.	Boom Eff. Conc.	WSP Eff. Conc.
Total P	8.46	3	7.55	6.87	9.55	12.1
		2	7.64	7.75	9.64	
NO_3 N	0.04	3	0.24	0.21	0.74	0.06
		2	0.19	0.26	0.44	
NH_3 N	16.5	3	6.89	8.47	11.4	13.5
		2	9.56	8.56	13.4	
Org. N	7.28	3	3.47	3.65	2.66	3.93
		2	4.01	3.64	3.12	

ponds has little practical significance. The plot effluent ammonia levels ranged from 6.89 to 13.4 mg/l compared to 13.5 mg/l for the pond. This indicates an average reduction of 41 percent for the plots compared to only 18 percent for the pond. With respect to organic nitrogen, the two processes performed similarly with the pond achieving a 46-percent reduction compared to 53-percent for the plots. From the standpoint of the overall nitrogen balance, the winter performance of the plots was superior to that of the pond.

Referring to Table 11 for a comparison of the two processes under summer conditions, it may be noted that the BOD reduction of the pond dropped to 76 percent while the reduction by the plots rose to 82 to 93 percent. All effluent levels were below 30 mg/l, but the plots clearly outperformed the pond, presumably due to increased levels of phytoplankton in the pond effluent. The suspended solids data reveal a major advantage of the plots. The pond exhibited effluent suspended solids levels higher than the 105-mg/l influent while the plots achieved effluent levels of 3.6 to 10.6 mg/l with reductions averaging 94 percent. The fecal coliform data present basically the same picture as observed for the winter comparison, that is, the pond significantly outperformed the plots but neither process produced effluent levels approaching 10^2/100 ml.

Table 11. Comparison of overland flow and wastewater stabilization pond, summer application.

Anal. Par.	Infl. Conc.	% Slope	Riser Eff. Conc.	Trough Eff. Conc.	Boom Eff. Conc.	WSP Eff. Conc.
BOD mg/l	117	3	14.2	21.0	8.6	27.7
		2	18.2	18.3	8.3	
SS mg/l	105	3	9.4	10.6	3.6	114
		2	6.4	6.6	3.6	
F. Coli 10^6/100ml	5.0	3	1.4	1.8	1.2	0.033
		2	1.2	1.2	0.49	

The nutrient parameters tabulated in Table 12 reveal a similar situation. The pond effluent contained lower levels of phosphorus than did the plot effluents; however, neither process was appreciably effective for phosphorus reduction under summer or winter conditions. Comparison of the effluent levels of nitrate indicates a pattern almost identical to that observed for the winter. Specifically, the pond effluent level was much lower than those for the plots; however, all levels were at or below 1 mg/l. The ammonia data indicate that compared to the winter operation, both processes exhibited improved performances, especially the pond which produced lower effluent levels than the plots. All effluent levels ranged from 1.7 to 7.4 mg/l with the pond achieving a 90-percent reduction compared to an average of 68 percent for the plots. The organic nitrogen data again reveal the influence of high levels of phytoplankton in the pond effluent; the plots demonstrated a 52-percent reduction in organic nitrogen while the pond produced a 62-percent

Table 12. Comparison of overland flow and wastewater stabilization pond, summer application.

Anal. Par. mg/l	Infl. Conc.	% Slope	Riser Eff. Conc.	Trough Eff. Conc.	Boom Eff. Conc.	WSP Eff. Conc.
Total P	8.3	3	7.9	8.5	9.2	6.3
		2	8.7	8.9	9.2	
NO_3 N	0.05	3	0.18	0.16	1.04	0.08
		2	0.18	0.24	0.67	
NH_3 N	16.7	3	4.2	7.4	3.1	1.7
		2	6.9	6.9	3.4	
Org. N	8.5	3	4.0	4.8	2.9	13.8
		2	4.6	5.0	3.1	

increase. This resulted in the plots again having a superior reduction in the concentration of total nitrogen with 38 percent attributable to the pond and 61 percent attributable to the plots.

Microbial Analyses. The total bacterial counts conducted on the raw system indicated influent levels of 10^6 to 10^7/ml, effluent levels of 10^5 to 10^6/ml, and corresponding reductions of 78 to 97 percent across all application methods, slopes, and seasons. The total coliform counts were similar in that the influent averaged in the range of 10^6/ml, the effluents varied from 10^4 to 10^5/ml, and the percentage reductions were from 76 to 96 percent for all application methods, slopes and seasons. These reduction levels are in general agreement with those observed for the fecal coliform analyses and confirm the relatively low ability of plots to significantly lower the levels of enteric bacteria.

The concentration of enteric viruses isolated from the raw treatment system displayed a range of 10^1 to 10^2 PFU/l with an apparent seasonal distribution which peaked in the late summer. The plots displayed removal efficiencies of 100 percent up to the period of peak loading at which time the removal efficiencies reduced sharply. No apparent differences were observed with respect to method of application or slope. No enteric viruses were isolated from either the influent or the effluents of the secondary system.

The ambient air bacterial colony counts taken upwind and downwind of the 2-percent boom indicate that the total bacterial counts varied from no significant change to reductions of 34 percent while the total coliform counts consistently showed statistically significant increases. Dispersion modeling, however, indicated that the highest observed average of 731 coliform colonies/m^3 would be relatively insignificant 60 meters downwind. The ambient air particle counts taken at the same locations indicated increases in the downwind concentrations for the summer but decreases for the winter; however, no statistical significance would be associated with any of the changes. The size/count distributions exhibited median particle diameters in the respirable size range. Collectively, these observations indicate a potential health hazard for employees if tasks are performed on or near the boom or riser plots during application. Within the capabilities of the sampling and analysis techniques employed in this study, no airborne viruses were isolated either upwind or downwind of the 2-percent boom.

Soil Analyses. As shown in Table 13, the results of the soil analyses conducted before and after 2 years of wastewater application indicate that the surface soils of both the raw and secondary systems demonstrated increases in calcium, sodium, and copper. Decreases were observed for phosphorus, manganese, and potassium. The decrease in phosphorus is particularly noteworthy for it supports the observations made on the phosphorus concentrations of the wastewater from both the raw and secondary systems. The results of the subsoil analyses reveal a more varied pattern with the most consistent changes being an increase in sodium and a decrease in iron and manganese for both systems.

Table 13. Soil analyses.

Sample Location	Raw System		Secondary System	
	Increase	Decrease	Increase	Decrease
Surface (15 cm)	Na Ca Cu	P Mn K	Ca Cu Na	P Mn K Zn Fe
Subsurface (30 cm)	Na P	Mn K Fe	Cu Na Zn	Fe Mn

SUMMARY

Under the operational constraints of this study, overland flow for the treatment of raw domestic wastewater demonstrated the ability to achieve BOD removal efficiencies averaging 71 percent for the 5-month winter operation and 87 percent for the 7-month summer period. These correspond to effluent levels of 37.2 and 14.8 mg/l respectively. The annual as well as the summer average BOD compare favorably with an effluent limitation of 30 mg/l. If the performance of the system under winter conditions was not acceptable for a particular situation, operational modification such as a lower loading rate for the colder months would be indicated.

The suspended solids data indicated average effluent concentrations ranging from 12.3 mg/l for the winter to 6.7 mg/l for the summer with corresponding removal efficiencies of 86 and 94 percent. These values represent a high level of year around performance with respect to this parameter and show suspended solids reductions achieved by overland flow to compare favorably with typical effluent limits and with the treatment efficiency of mechanical secondary treatment processes.

On the other hand, the fecal coliform data showed average reductions of 59 percent for the winter and 76 percent for the summer. These findings were supported by the results of the total bacterial and total coliform analyses. Considering that the influent as well as the effluent levels of fecal coliform were all in the range of 10^6/100 ml, these reductions were relatively small compared to the reductions required to meet an effluent limit in the range of 10^2/100 ml. If such limits are imposed, additional treatment for coliform reduction is definitely indicated.

The phosphorus data exhibited little if any reduction for the winter with various levels of increase typifying the summer operation. This suggests that under the conditions of this study, the anticipated uptake mechanisms were absent or ineffective. Crop uptake levels were apparently small compared to the amount available, and those requirements were met by sources other than the wastewater.

The results of the nitrogen analyses showed that effluent nitrate levels were at or below 1 mg/l for both the winter and summer periods. The similarity of the results for the colder months and for the growing season suggests that the level of plant uptake of nitrate was small compared to the amount available. The low effluent level indicates either a low level of nitrification or a high level of nitrification-denitrification. Since the effluent ammonia levels were relatively high for both seasons, the former is indicated. According to the proposed theory of nitrogen transformations on overland flow plots (3,5,10-12), this would indicate that the plots utilized in this study were overloaded with respect to maximum nitrogen removal by nitrification-denitrification mechanisms.

For the most part, changes in the nitrogen balance were reflected in the changes in the ammonia and organic nitrogen levels. The effluent levels of ammonia-nitrogen varied from an average of 9.71 mg/l for the winter to 5.32 mg/l for the summer. The corresponding treatment efficiencies ranged from 41 to 68 percent, with higher ambient temperatures apparently responsible for increased volatilization. The organic nitrogen data revealed a consistent level of performance for both seasons, with effluent levels averaging 3.42 mg/l for the winter and 4.07 mg/l for the summer. The percentage reductions were almost identical with 53 for the winter compared to 52 for the summer. Overall, the plots achieved total nitrogen reductions of 43 percent for the winter and 61 percent for the summer.

Although statistically significant differences were found among the effluent levels for many of the various analytical parameters, no single method of application or slope tested demonstrated a consistently superior performance. This indicates that future consideration of method should be based on cost and ease of installation, operation, and maintenance as well as performance.

Overland flow operated as a tertiary treatment system for wastewater stabilization pond effluent indicated only limited year-round benefits under the conditions tested. No statistically significant differences were observed between the two application methods or slopes employed. Even though the reductions in effluent levels were comparatively low for a locally sensitive receiving water, these reductions, along with the benefits from harvesting a cover crop from an agriculturally marginal soil and terrain, could provide an alternative treatment that would be within the technical and economic constraints of small communities.

The comparison of overland flow with the wastewater stabilization pond for the treatment of raw domestic wastewater indicated that neither system, on a year-round basis, produced a consistently better effluent for all parameters tested. The effluent from the pond was lower in fecal coliform and nitrate levels, while the plots were lower in suspended solids and total nitrogen concentrations. Neither system performed well with respect to phosphorus removal; the lower BOD values were produced by the pond during the winter and by the plots during the longer summer operation. Considering all factors, including cover crop production, overland flow was indicated as the method of choice.

CONCLUSION

Overland flow for the year-round treatment of raw domestic wastewater was shown to be comparable to mechanical secondary treatment and somewhat superior to the wastewater stabilization pond from the standpoint of the conventional regulatory parameters of BOD and suspended solids. Although ammonia and organic nitrogen levels were appreciably reduced, tertiary levels of treatment were not observed in the raw or secondary systems, especially for the nutrient and microbiological parameters.

It should be pointed out, however, that the treatment efficiencies observed for the raw and secondary systems utilized in this study are somewhat lower than those observed for the relatively few but widely reported (3, 5, 12-24) previous studies of municipal wastewater treatment by overland flow. This serves to emphasize the point that the performance of a land application system is influenced by many more local and possibly unique variables than is a mechanical system, and, at the present state of the art, gross extrapolation of design features from one system to another may not result in the anticipated level of performance. Obviously, much additional work remains to be accomplished especially in the area of overland flow.

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Question (by Mr. Jack Witherow): There is a tremendous difference between performance results at Pauls Valley and at Ada. My question is, why? They used the same slope, application rates, and application techniques.

Response (by Dr. Lawrence): There were minor differences in the dosing sequence and the soils. But there are other factors that are probably the dominant reasons. We did not have researchers monitoring the day-to-day operation of the system. We had waste treatment plant operators on the day-to-day operation of the system, and that makes a little bit of difference on how well the system will run.

As for the strips that you saw on the slide--that is an aerial photograph taken the first year of operation. It indicates one of the major operational problems in this system, and that is channeling. The tall stuff that you saw was grass; it was taller in some areas because that is where the channels are. It took literally a year to eliminate that kind of problem from the system--particularly on the boom plots which were shown in the aerial view. This was because the distribution from the booms was not even across the upper end of the slope. It was heavier in the middle, which took quite a while to eliminate.

Additional Comments (by Mr. Bledsoe): From the slides that were shown earlier, I think that you can see that removal of ammonia is dependent upon the contact time on the treatment slope. Unless you achieve a very good sheet flow--which I don't feel they achieved at Pauls Valley where they had channeling on some of it--short-circuiting occurs and the retention time is reduced sharply. The ammonia removal results at Pauls Valley indicate that the retention time of the waste was much shorter than what it was for the facility at Ada. This supports the contention that short-circuiting was affecting the observed results.

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Development of a Rational Basis for the Design and Operation of the Overland Flow Process

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BACKGROUND

The overland flow land treatment process has been demonstrated to be a viable method for the treatment of a wide variety of wastewaters ranging from high-strength food processing and agricultural wastewater to secondary treated municipal wastewater. When used for the treatment of raw or primary treated municipal wastewater, overland flow has been shown to be capable of producing effluents equal or superior in quality to those produced by conventional secondary treatment processes at a substantially lower cost (1,2). The U.S. Environmental Protection Agency (EPA) has recognized and encouraged the use of the overland flow process as a viable alternative for municipal wastewater treatment when site conditions are suitable for its use (3). Yet implementation of the overland flow process for municipal wastewater treatment has been very limited. As of January 1980, there were only two full-scale, permanent systems and four pilot-scale, experimental systems in operation (4). Several systems currently are under design or construction.

The reluctance on the part of the engineering design community to employ the overland flow process is due primarily to the limited amount of full-scale operating experience and the lack of a rational basis for the design and operation of the process. A rational design approach has not been developed because there has been very little information generated on the relationships between process performance and the major process design and operating parameters and environmental factors. There is also disagreement in the literature on what are the design and operating parameters that govern treatment performance and on how they should be expressed. As a consequence, the design and operation of overland flow systems have been patterned closely after existing successful systems, and rules of thumb and general guidelines have served as design criteria. Although these existing systems do provide high levels of treatment, the safety factors inherent in their design and operation are unknown. Because the operating limits of the process have not been defined, optimization of process design has not been possible.

What is needed to advance overland flow technology is a clear definition of the design and operating parameters and environmental factors that govern overland flow treatment performance and an understanding of the relationship between these parameters and treatment performance. Such knowledge is necessary to develop functional relationships in the form of predictive models that can be used to predict reliably the effects of the governing design and operating parameters on treatment performance. Such predictive models would serve as a rational basis for the design and operation of overland flow systems and would allow system design to be optimized to produce an effluent of specified quality at a minimum cost.

In an effort to meet these needs, the Department of Civil Engineering at University of California, Davis has undertaken an overland flow research and demonstration project under the sponsorship of the California State Water Resources Control Board. The project is being conducted in two phases. Phase I involves pilot studies conducted indoors under semi-controlled environmental conditions. Phase II is a full-scale, 4.5 hectare (11 acre) field demonstration of the overland flow process for the treatment of raw and primary treated municipal wastewater. The purpose of this report is to present and discuss the results of the pilot studies and to present the formulation of a predictive model that can be used to describe the removal of wastewater constituents as a function of process design and operating parameters.

Objectives

The overall objectives of the project are to formulate and verify a predictive model that can be used as a rational basis for the design and operation of overland flow systems and to demonstrate the capabilities of overland flow as a treatment process for raw and primary treated municipal wastewaters.

The specific objectives of this study include:

1) Establishment and definition of overland flow design and operating parameters and units for their expression.

2) Construction of experimental facilities for the conduct of overland flow pilot studies.

3) Development of pilot study procedures and conduct of studies to determine the effect of defined parameters on overland flow treatment performance.

4) Formulation of predictive models describing treatment performance as functions of governing process design and operating parameters.

Scope

The results presented and discussed in this report are limited to studies on the removal of degradable organic material by the overland flow process. The parameters used in this study to measure degradable organic material include five-day biochemical oxygen demand (BOD_5) and total organic carbon (TOC). Thus, in the predictive models formulated as part of this report, treatment performance is described in terms of the reduction in the levels of BOD_5, and TOC. Treatment performance in terms of other parameters, including nitrogen, and coliform organisms, was studied as part of the project and the results are reported elsewhere (5, 6).

Two wastewaters were studied during the pilot project; a soluble, synthetic wastewater, and primary effluent from a municipal wastewater treatment plant. The predictive models developed in this study are applicable specifically to these types of wastewaters, but the models can be used to describe general relationships between governing design and operation parameters and process performance for most degradable wastewaters.

OVERLAND FLOW DESIGN AND OPERATING PARAMETERS

The first step in the development of a rational basis for the design of overland flow systems is to define the design and operating parameters that may affect process performance and establish units for their expression. A list of the basic design and operating parameters associated with the overland flow process is presented in Table 1 along with suggested units for their expression and the range of parameter values used in existing systems. A definition of each of these parameters is presented below along with a discussion of current practice.

Slope Length

As defined in this report, the overland flow slope is the physical surface to which wastewater is applied. It often has been referred to in the literature as a terrace. The overland flow slope is the reactor where treatment of the wastewater takes place. The minimum length of slope necessary to produce an effluent of a specified quality from a particular type of wastewater applied at given rate has not been established yet nor can it be predicted. Prediction of minimum slope lengths for treatment is one of the principal objectives of this study. Slope lengths that have been used successfully for treatment of food processing wastewaters range from 60 to 90 meters, while slope lengths that have been used for municipal wastewater treatment generally range from 30 to 45 meters.

Slope Grade

Slope grade is defined as the incline of the slope surface and is expressed as the percent of vertical use to horizontal run. Based on experience to date, process performance does not appear to be sensitive to changes in slope grade in the range of 2 to 8 percent (7) (8). A slope grade in the range of 2 to 6 percent has been recommended by some workers to avoid problems associated with erosion and channeling on steep slopes and ponding on shallow slopes (8).

Slope grades as shallow as 0.5 percent are used at the Werribee Farm in Melbourne, Australia (9). However, that system is not comparable to overland flow systems developed in the United States. Thus, an accurate assessment of the effect of low slope grades on performance can not be made on the basis of the Werribee experience. Although, at this time there is no strong evidence indicating that slope grades in the range of 0.5 to 1 percent would not be suitable for overland flow.

Table 1. Overland Flow Design and Operating Parameters.

Parameter	Unit	Typical Range	Range Studied
Slope length, z	meter	30 - 55	0 - 18.3
Slope grade	%	2 - 8	2 - 6
Application rate, q	mL/min•cm	10 - 40	13.1 - 39.4
	L/min•m	1.0 - 4.0	1.31 - 3.94
	m^3/hr•m	0.08 - 0.24	0.06 - 0.24
Application period, P	hrs/day	4 - 24	4 - 24
Application frequency	days/wk	3 - 7	5 - 7
Hydraulic loading rate	cm/day	1 - 7	2 - 11.7[a]
Organic loading rate	kg BOD_5/ha•d	15 - 70	15 - 90[a,b]
			30 - 90[a,c]

a. computed on the basis of 30 m slope length
b. for primary effluent
c. for synthetic wastewater

Application Period

Application period refers to the length of time during a day that wastewater is applied to the slope (e.g. 6 hr/day). Most existing systems are operated in the range of 6 to 12 hr/day. Continuous 24 hr/day application periods have been used successfully at a few sites (7, 9,), however additional research is necessary to assess long-term effects on performance and the overland flow slope.

Application Frequency

Application frequency refers to the sequence of application days and nonapplication days (e.g. 5 day on/2 day off). This is often reported in terms of application days/week (e.g. 5 days/week). Most experimental overland flow systems are operated on a frequency of 5 or 6 days/week, primarily for reasons of convenience rather than any demonstrated performance effect. Most full-scale systems would be operated on a frequency of 7 days/week except during harvest periods. Extended periods of nonapplication result in drying of the biological slime layer which can reduce process efficiency.

Application Rate

Application rate is the volume of wastewater applied to the slope divided by the application time period in minutes. To standardize this parameter it is necessary that it be expressed on a per unit slope width basis (e.g. ml/min•cm of slope width or L/min•m or m^3/hr•m). Although this parameter is not often reported in this form, it appears that it is the parameter that has the greatest influence on treatment performance. Application rates used in existing systems range from about 10 to 40 ml/min•cm or 0.08 to 0.24 m^3/hr•m. The latter units are the most convenient for use with full-scale systems.

Hydraulic Loading Rate

Hydraulic loading rate is the volume of wastewater applied per day or per week divided by the area of the overland flow slope (e.g. cm/day or cm/wk). Rates generally have been reported on a weekly basis. However, expressing the rate on a weekly basis provides no information on how much water is applied each day which is more important from the standpoint of process performance. Therefore, expression of the hydraulic loading rate on a daily basis is more meaningful. Historically, this parameter is the one most often reported and has been the design parameter used to determine the land area required for a given system. However, there is evidence (as discussed later) that this parameter, within the range of values commonly used, has much less effect on treatment performance than other parameters. Unfortunately, it has become entrenched in the minds of many as the principal overland flow design and operating parameter. The probable reason for this is that hydraulic loading rate is the principal design parameter for conventional irrigation or slow rate systems, and because the overland flow process developed as a departure from conventional spray irrigation, it is not unexpected that the design procedures used for the slow rate process would carry-over to the overland flow process. It should be noted that the hydraulic loading rate can be considered as a secondary, dependent operating variable determined by the independent parameters - application rate, application period, application frequency, and slope length.

The hydraulic loading rates used at existing systems vary with the nature of the wastewater applied. The rates used for food processing wastewaters ranged from about 1 to 2 cm/day. Rates used for municipal wastewaters range from about 1 to 2 cm/day for raw wastewater, 1.5 to 3 cm/day for primary effluent, and 1.5 to 6 cm/day for secondary effluent.

Organic Loading Rate

Organic loading rate is the mass of organic material expressed as BOD_5, TOC, COD, or TOD that is applied to the slope per day divided by the area of the slope (e.g. kg BOD_5/ha•day). It is a function of the organic concentration of the wastewater and the hydraulic loading rate. Organic loading rates in the range of 60 to 150 kg/ha•day have been used for food processing wastewaters. Rates up to 70 kg/ha•day have been used for raw municipal wastewaters. Rates used for primary and secondary municipal effluent are correspondingly less.

INITIAL MODEL DEVELOPMENT

To provide focus for the experimental work a preliminary model describing the removal of organic material with the overland flow process was developed on the basis of theoretical considerations.

In terms of removal of organic material from wastewater, the overland flow slope can be considered a biological film-flow reactor similar in many respects to a trickling filter. The mechanisms responsible for the removal of organic material is the same in both processes. Suspended and colloidal organic matter are separated from the liquid fraction by contact with and subsequent adsorbtion onto the biological slime layer or film on the surface of the media in the case of trickling filters and on the surface of the soil and vegetation in the case of the overland flow slope. Contact of the solid particles with the slime layer is brought about by a combination of physical mechanisms including sedimentation and interception. Adsorbed solids ultimately are solubilized by microbial action and the soluble material diffuses into the film where it is converted to end products and new cell material. Soluble organic matter initially present in the wastewater diffuses directly into biological film.

Because the removal mechanisms in the overland flow and trickling filter processes are similar, it is expected that descriptions of organic removal kinetics also would be similar. On the basis of this expectation, a preliminary model describing the removal of degradable organic material by the overland flow process is derived below using an approach similar to that presented by Schroeder (11) for the development of a trickling filter design equation.

Performing a mass balance over an idealized section of overland flow slope as shown in Figure 1 and assuming steady state conditions, the following equation is obtained

$$(Q\ C)_z - N_y w \Delta z = (Q\ C)_{z+\Delta z} \qquad \text{(Equation 1)}$$

where Q = flow rate, ml/min

C = organic concentration in the liquid film, mg/l

N_y = flux of organic material into slime layer, mg/cm^2

z = distance down slope, cm

w = wetted perimeter, cm

If Δz is allowed to approach zero, then:

$$-\frac{d(Q\ C)}{dz} - N_y w = 0 \qquad \text{(Equation 2)}$$

If the flux rate into the slime layer is equal to the reaction rate within the slime layer and the reaction rate follows Monod kinetics and there is no organic concentration gradient within the liquid film, then the following equation can be written for the flux at the slime surface

$$N_y = \frac{Ek\ C}{K_m + C} \qquad \text{(Equation 3)}$$

where E is an effectiveness factor

k is a rate constant

K_m is saturation coefficient.

As suggested by Schroeder (11), E is approximately proportional to the organic concentration C under normal operating conditions for trickling filters. Thus, we may write

$$N_y = \frac{K_1 C^2}{K_m + C} \qquad \text{(Equation 4)}$$

Because in most cases, $C >> K_m$, equation 4 reduces to

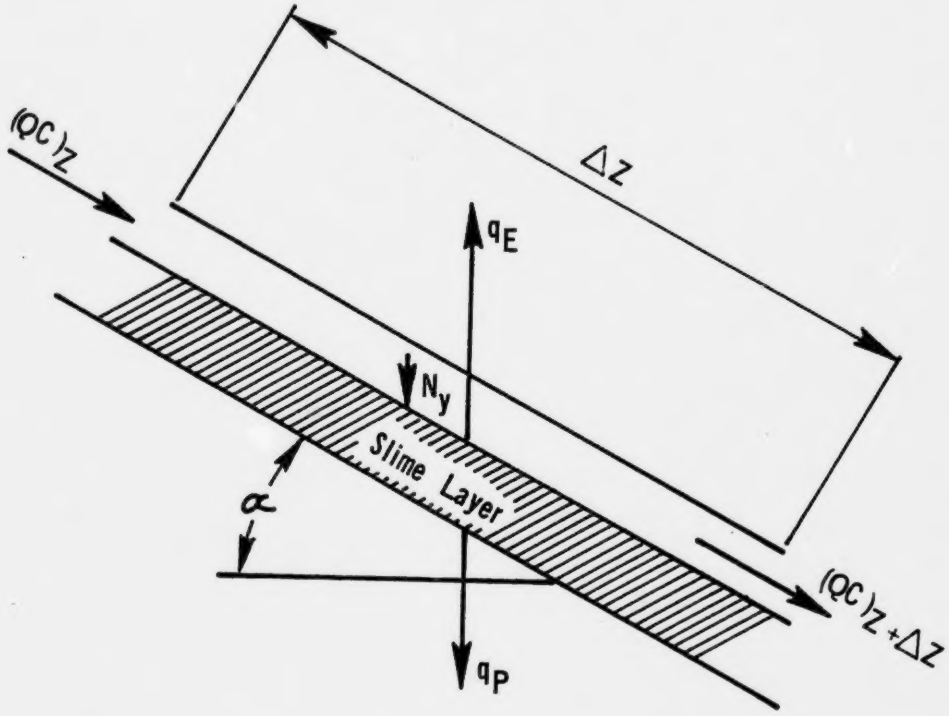

Figure 1. Idealized Section Through An Overland Flow Slope.

$$N_y = K_1 C \qquad \text{(Equation 5)}$$

Substitution of equation 5 into equation 2 yields

$$\frac{d(Q\ C)}{dz} = -K_1 C\ w \qquad \text{(Equation 6)}$$

$$C \frac{d\ Q}{dz} + Q \frac{d\ C}{dz} = -K_1 C\ w \qquad \text{(Equation 7)}$$

The term dQ/dz is equal to the loss of water from the system due to percolation and evapotranspiration. It is assumed that this lost water does not contain organic material. Thus,

$$\frac{d\ Q}{dz} = -(q_E + q_p)w \qquad \text{(Equation 8)}$$

where q_E = evapotranspiration rate, cm/min

q_p = percolation rate, cm/min

Substituting equation 8 into 7 we obtain

$$Q \frac{d\ C}{dz} - C\ (q_E + q_p)w = -K_1 C\ w$$

Letting $q_E + q_p = K_2$

$$\frac{d\ C}{dz} = -\frac{(K_1 - K_2)\ \ C\ w}{Q} \qquad \text{(Equation 9)}$$

Integration yields

$$\frac{C_z}{C_o} = \exp\left[-\frac{(K_1 - K_2)\ \ z\ w}{Q}\right] \qquad \text{(Equation 10)}$$

where C_z = organic concentration at a distance Z down the slope, mg/L

C_o = organic concentration at the top of this base, mg/L

Water loss from the slope due to evaporation and percolation would increase the concentration of organic matter in the wastewater and according to equation 10 would have the effect of reducing the organic removal efficiency on a concentration basis. It should be noted, however, that increasing the concentration of organic matter would tend to increase the concentration gradient across the film and thus increase the effective rate of removal of organic material. The net effect would be the same as increasing the observed value of K_1. Thus, determination of individual values for K_1 and K_2 would be a very difficult undertaking. In addition, the determination of the wetted perimeter (w) on an overland flow slope having films on vegetation as well as the soil surface would be impossible. The logical procedure to follow, as suggested by Atkinson (12) in a discussion of trickling filters, is to determine experimentally an overall rate coefficient K that incorporates the individual parameters. Using this empirical approach Eckenfelder (13) proposes a design equation of the following form for trickling filters.

$$\frac{C}{C_o} = \exp\left(- \frac{K\ A_v\ 1 + m\ D}{Q^n}\right)$$

The exponents n and m are constants related to the geometry of the medium.

The analogous design equation for the overland flow process would be of the form

$$\frac{C_z}{C_o} = \exp\left(- \frac{Kz}{q^n}\right) \qquad \text{(Equation 11)}$$

where K = overall rate constant

Z = distance down slope

q = application rate per unit width of slope, ml/min•cm

n = empirical constant

Thus, organic removal efficiency is expressed as a function of distance down slope and application rate only.

It is interesting to note that similar equations can be derived using a different approach. If it is assumed that organic removal is related to the contact time of wastewater with the slime layer and that the organic removal follows first order reaction kinetics, the following relationship can be written

$$\frac{C}{C_o} = \exp\left(-K'T\right) \qquad \text{(Equation 12)}$$

where K' = reaction rate constant

T = contact or detention time

The next step in this approach is to determine a relationship between detention time and other governing operating parameters. Several relationships have been developed to determine detention time of water flowing on a grass covered slope. Martel et al (14) propose the following equation

$$T = \frac{0.078\ z}{s^{1/3}\ q} \qquad \text{(Equation 13)}$$

where T = detention time

Z = distance down slope

s = slope grade

q = average flow rate per unit width

Substituting equation 13 into 12 yields the following organic removal model

$$\frac{C}{C_o} = \exp\left(-\frac{0.078\ K'\ z}{s^{1/3}\ q}\right) \qquad \text{(Equation 14)}$$

Nakano et al (15) propose the following equation for detention time

$$T = \frac{z}{(sc^2q)^{1/3}} \qquad \text{(Equation 15)}$$

where c = roughness coefficient

Substituting equation 15 into 12 yields

$$\frac{C}{C_o} = \exp\left[-\frac{K'z}{(sc^2q)^{1/3}}\right] \qquad \text{(Equation 16)}$$

The Soil Conservation Service (16) uses the following equation to describe the movement of irrigation water on a vegetated slope.

$$T = \frac{n^{0.6}a}{q^{0.4}\ s^{0.3}} \qquad \text{(Equation 17)}$$

where n = roughness coefficient

Substituting equation 17 into 12 yields

$$\frac{C}{C_o} = \exp\left(-\frac{K'z\ n^{0.6}}{q^{0.4}\ s^{0.3}}\right) \qquad \text{(Equation 18)}$$

Equations 14, 16, and 18 are all of the form

$$\frac{C}{C_o} = \exp\left(-\frac{c'K'z}{q^n s^m}\right) \qquad \text{(Equation 19)}$$

where c' = constant related to surface roughness

If the constants c' and K' are combined into a single constant K, then the organic removal model described by equation 19 and the model described by equation 11 are essentially the same except for the slope grade term (s^m). This raises the question of whether slope grade should be a parameter in the model. As indicated previously, it has been shown by several studies that slope grade has had no significant effect on treatment performance. However, these findings cannot be considered conclusive.

Both theoretical and practical questions exist regarding the use of wastewater detention time as the key parameter in a predictive model for organic removal on an overland flow slope. Martel et al (14) are the principal proponents of the detention time model. In the derivation of their model it is suggested that the overland flow slope is analagous to a biological plug-flow reactor for which liquid detention time is the governing operating parameter. However, a plug-flow reactor is a suspended-culture process in which the biological reactions occur in the bulk liquid. As discussed earlier in this section, the overland flow slope is considered more appropriately as a film-flow reactor in which reactions occur primarily on the soil and vegetative surfaces rather than in the bulk liquid. The important factors affecting the utilization of organic substrate in a film-flow reactor are the contact time of the substrate with the film, the transport rate of substrate to the film surface, and the diffusion rate of substrate and oxygen into the film layer. Bulk liquid detention time on the slope is important only as it affects these factors. At a given substrate mass loading or application rate, flow velocity increases and the detention time of the bulk liquid decreases with increasing slope grade according to the hydraulic relationships presented previously. However, at a constant flow rate, the depth of flow also decreases with increasing slope grade and velocity. Shallower liquid depth will tend to enhance the transport of suspended material to the film surface because the solids will have a shorter distance to settle to the surface. Higher flow velocities will tend to reduce the depth of the stagnant liquid layer between the bulk liquid and the film surface, thereby reducing the substrate concentration gradient between the bulk liquid and the film surface and maintaining a higher substrate concentration at the film surface. Diffusion rate of substrate into the film would be expected to depend on the substrate concentration at the film surface and this assumption is supported by work of Williamson and McCarty (17). Based on these considerations, it would appear that although liquid detention time and, therefore, contact time decrease with increasing slope grade, the corresponding reduction in flow depth may enhance the rate of substrate utilization and off-set the effect of reduced contact time. Thus the effect of slope grade on organic removal efficiency may be nil or much less than predicted by its effect on detention time alone.

From a practical standpoint, the use of a predictive model based on detention time is somewhat cumbersome. First of all a correlation must be developed between detention time and organic removal efficiency. Detention time must be estimated by means of tracer studies and the value will change with application rate, slope length, temperature, and possibly other variables. The detention time thus determined is not an exact value, but depends on the type of tracer and procedures used in the study and the method used to determine the detention time from the tracer response data. To verify the model at other overland flow sites a standard procedure for conducting tracer studies would need to be established. For the model to be of practical benefit, a correlation also must be developed between detention time and measurable design and operating parameters, such as application rate and slope length. Since the net result of the detention time model is an empirical correlation between organic removal efficiency and the design and operating parameters, it would seem that a simpler and more direct approach to model development would be to eliminate consideration of detention time and develop direct correlations between organic removal efficiency and the measurable design and operating parameters. The net relationship would be the same and model verification at other overland flow systems would be less involved.

It is important to note that hydraulic loading rate does not appear as a parameter in either form of the removal model derived above. Application rate is the only operating variable that appears in the model. As discussed previously, hydraulic loading rate historically has been used as the principal design parameter for the overland flow process and relationships between hydraulic loading rate and treatment performance have been suggested (Hinrichs et al (4)). Thus, the question is raised as to whether hydraulic loading rate should be included as a model parameter.

The preliminary models derived above and the questions raised about the parameters to be included provide a focus for the pilot studies. Questions to be answered by the pilot studies include the following:

1. Can removal of organic material by the overland flow process be described as an exponential decay function of distance down the slope?

2. What is the effect of application rate on organic removal efficiency?

3. What effect, if any, does slope grade have on organic removal efficiency?

4. What effect, if any, does hydraulic loading rate have on organic removal efficiency?

The answers to these questions will provide the basis for the development of a predictive model describing removal of organic material by the overland flow process.

PILOT STUDY FACILITIES

The experimental overland flow slopes and associated equipment were housed indoors in the Civil Engineering laboratory at the University of California, Davis. The major components of the pilot facilities include the overland flow slopes, the artificial light banks, the wastewater feed system, and the lysimeter. A schematic flow diagram of the pilot study facilities indicating the arrangement of system components is shown in Figure 2.

Overland Flow Slopes

The overland flow slopes consist of three beds each measuring 1.5m wide x 6m long x 20cm deep. The design and construction of the beds were patterned after those used by Carlson et al (18) for indoor studies at Vicksburg, Mississippi. The beds were designated A, B, and C as indicated in Figure 2. The floor and sides of the beds were constructed of 1.9 cm (3/4 in) plywood. The floor was supported by transverse 5 cm x 15 cm (1 in x 6 in) joists at 61 cm centers and by double 5 cm x 30.5 cm (2 in x 12 in) beams along each side. The beams were supported by a pivot stand at the down slope end and a height adjustable stand at the opposite end. This arrangement allowed the slope grade to be varied between 0 and 6 percent. The plywood sides were supported by a 5 cm x 20 cm (2 in x 8 in) backing encompassed by a double 5 cm x 15 cm (2 in x 6in) collar. Ports were installed in the floor of the beds to allow sampling of the subflow. The ports were located at 15 cm intervals across the bed at 61 cm intervals along the length of the bed and consisted of Plexiglass nipples imbedded in silicone sealant and stoppered with a rubber septum. Eight ports were installed along the end of the bed to allow discharge of subflow. Subflow discharge ports were fitted with flexible tubing connected to a drain. All ports were covered with Fiberglass cloth to retain the soil. Subflow discharge ports also were covered with a layer of fine sand. Epoxy enamel was used to paint the interior of the beds. The beds were divided into four 38.1 cm (15 in) channels by means of Plexiglass dividers. Plexiglass trays to collect runoff were
end of each channel on the interior of the down slope side 12.7 cm (5 in) from the bottom. Runoff trays were constructed of 3.2 mm (1/8 in) Plexiglass and measured 1.9 cm (3/4 in) wide, 1.3 cm (1/2 in) deep and 38.1 cm (15 in) long with a lip extending out 1.9 cm (3/4 in). Each tray was fitted with a 1.3 cm (1/2 in) diameter P
down slope end of the bed and was connected to a drain manifold with flexible tubing. The drain manifold discharged either to a floor drain or to a sump equipped with a transfer pump.

The beds were filled to a depth of 12.7 cm (5 in) with Clear Lake clay soil obtained from a site adjacent to the City of Davis wastewater treatment plant. Soil was passed through a screen with 1.3 cm (1/2 in) openings and placed in the beds in uniform lifts of 5 cm (2 in). Each lift was wetted slightly and compacted uniformly with a water-filled lawn roller. After compaction, each layer was scarified with a rake to promote bonding and continuity with the next layer. Following placement of the last soil lift, the

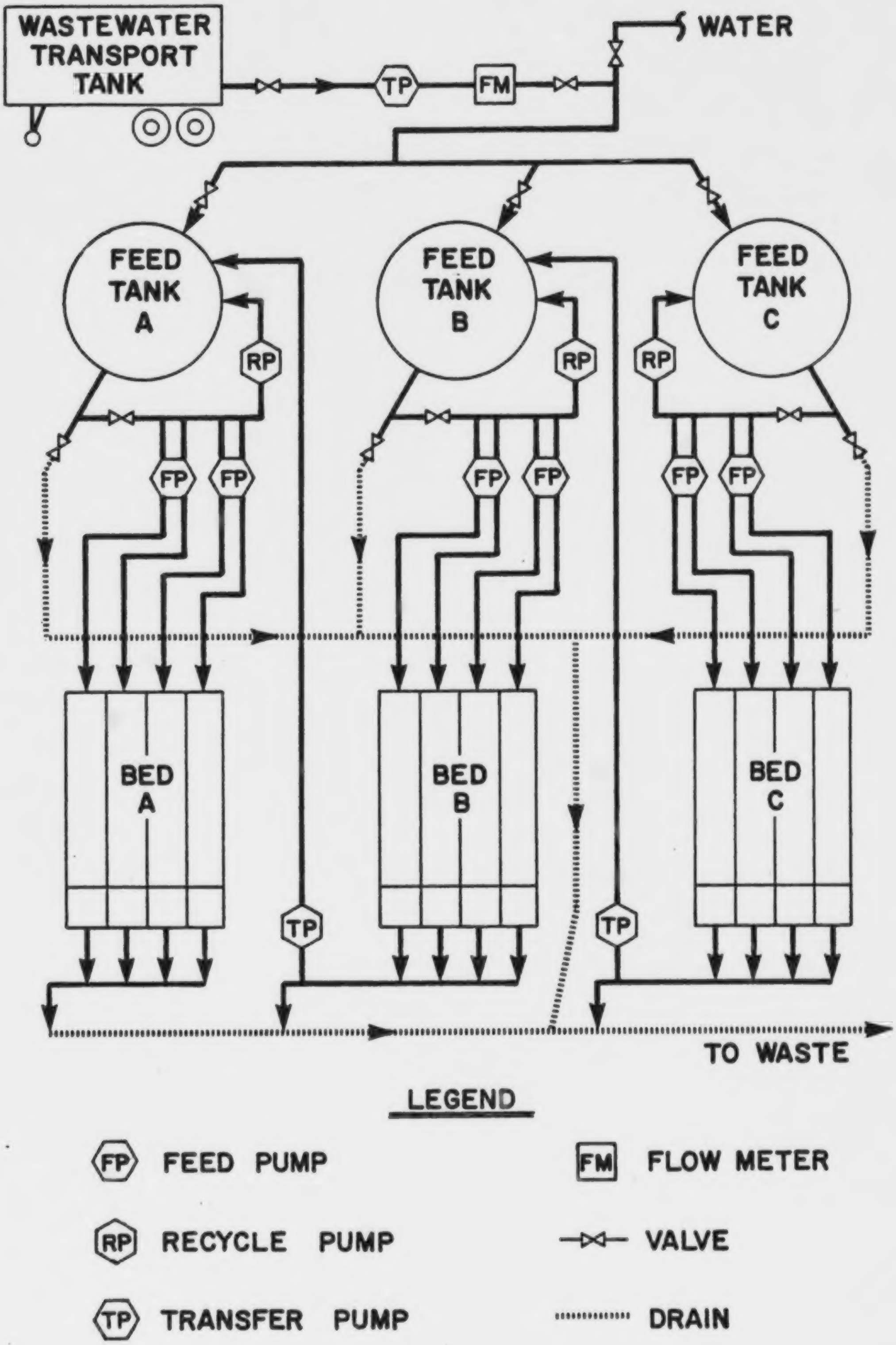

Figure 2. Overland Flow Pilot Facilities Flow Diagram.

Common Bermuda grass sod was placed on the prepared soil. A slit was cut along the lower end of the sod such that the lips of the Plexiglass tray extended 1.3 cm into the sod about 1.3 cm below the surface. The sod was maintained by regular sprinkling with tap water for about 2 months prior to testing.

Ports for sampling of surface flow were located at 1.2 meter intervals in each channel down the length of each bed. Thus each bed contained 16 surface flow sampling ports. The ports consisted of hollow plastic cylinders approximately 1.5 cm in diameter inserted into the soil to act as wells for water flowing over the surface.

Artificial Light Banks

Lighting necessary for plant growth was provided by artificial light banks suspended by chains above each bed. The light provided at the slope surface by the light banks ranged between 2.1×10^4 and 2.7×10^4 lux. Light banks consisted of a wood and metal frame to which incandescent and fluorescent fixtures were attached. The frames were ladderlike units constructed by placing 2.5 cm x 10 cm x 1.5 m (1 in x 4 in x 5 ft) boards at 61-cm intervals and interconnecting them with 3.8 cm x 3.8 cm x 3.2 mm (1.5 in x 1.5 in x 1/8 in) angle iron. Light fixtures were 2-lamp VHO (1500 ma) fluorescent fixtures and porcelain incandescent lamp fixtures with 100-watt lamps. Each bank contained 22 incandescent lamps, 20 fluorescent fixtures 2.44 m long. The light banks were maintained parallel to the slope by adjusting the length of the individual suspension chains. A steel cable and a chain hoist were used to raise and lower the light banks. A single 24-hour, on-off time switch was used to control the lights.

Wastewater Feed Systems

Components of the wastewater feed system include feed tanks, recirculating pumps, feed pumps, transfer pumps, and feed manifold. The arrangement of these components and associated values and piping are shown in Figure 2. Fiberglass tanks having diameters of 1.5 m and a volumetric capacity of approximately 1600 liters were used for feed tanks. Each tank had a bottom drain that discharged to common drain manifold. The contents of the tanks were mixed by means of a recirculating system that pumped water from the drain line and discharged it into the top of the tank through a nozzle. Recirculating pumps were rubber impeller, centrifugal type that were operated intermittently by means of an interval time switch. Feed pumps were Master-Flex, dual-channel, variable speed peristaltic pumps. Wastewater was withdrawn from the bottom of the feed tanks by the feed pumps and discharged into a feed manifold that distributed the water uniformly across the top of each slope. The feed manifolds were constructed of tygon tubing and polyethylene tees and consisted of 8 application ports per channel and 32 ports per bed.

During treatment studies with municipal wastewater, primary effluent was transported daily to the pilot facilities in a 2800-liter tank truck.

Wastewater was pumped from the tank truck by a transfer pump and known volumes of wastewater were metered into each feed tank by means of a totalizing flow meter.

Transfer pumps were also located at the down slope end of beds A and B for the purpose of transferring effluent from those beds to feed tanks B and C. Through this arrangement, the three beds could be operated in series, thus simulating a down slope travel distance of 18 meters. These transfer pumps were small sump pumps (40 liter/min) controlled by float switches.

PILOT STUDY PROCEDURES

Pilot studies were conducted in two phases. The first phase involved treatment studies with synthetic soluble wastewater and the second phase involved studies with primary treated municipal wastewaters. The reasons for first performing studies with synthetic wastewater were:

1. Use of synthetic wastewater would eliminate effects on treatment performance due to changes in wastewater characteristics and thus allow effects due to changes in operating parameters to be more readily observed.

2. Use of synthetic wastewater would allow experience to be gained with the system without the additional concern of handling municipal wastewater.

3. Comparison could be made between the treatment of a soluble wastewater and a wastewater such as primary effluent that contains a large fraction of organic material in suspended or colloidal form.

The same basic experimental approach was used in both phases of the study. The objectives of the study, as outlined previously, were to identify the design and operating parameters that effect overland flow treatment performance and to develop functional relationships between these governing parameters and treatment performance. On the basis of the preliminary models developed previously, the parameters slope length, slope grade, application rate, and hydraulic loading rate were identified as probable or potential governing parameters. Therefore, the basic study approach was to devise and conduct treatment tests that would reveal the nature of the effect of each parameter on treatment performance. The treatment test procedure used to achieve this consisted of operating the three beds so as to vary one operating parameter while holding all others constant. The parameters slope grade, application rate, and hydraulic loading rate were tested in this manner. The effect of slope length was studied as part of all experiments by taking samples of the surface flow at intervals down the slope and analyzing for organic material. Each experiment was conducted for a period of 4 to 8 weeks or until no trends in treatment performance were observed. The details of each treatment study are described below. Some general experimental procedures were common to all studies and these are described first. Experiments in addition to the parameter studies were conducted and are described below. These include studies on extended slope length, continuous application, detention time, water balance, evapotranspiration, and effluent characterization.

General Procedures

Several procedures and operations were common to most of the studies performed. These included sampling, feed system maintenance, cover crop harvest, and light bank operation.

• Sampling

Influent samples were withdrawn from the discharge ports of the distribution manifolds with a syringe (50 mL capacity). The discharge ports were designated sample Station 0. Equal volume samples were taken from each of the four manifold units associated with each bed and composited into a single sample.

Surface flow samples were taken with a syringe from the imbedded sampling port wells located in the center of each channel at 1.22 m intervals down the slope. The sampling ports were designated as Stations 1, 2, 3, 4 and 5 with Station 1 located 1.22 m from the top of the slope, Station 2 at 2.44 m, Station 3 at 3.66 m, Station 4 at 4.88 m and Station 5 at 6.10 m. Station 5 was the runoff collection tray. Equal volume samples were taken from each of the four ports at a Station and composited into a single Station sample. Prior to the collection of the sample at each port, water in the well was extracted and discharged and the well allowed to refill with surface flow. Effluent samples were extracted with a syringe from the runoff collection tray (Station 5). Equal volume samples were collected from each tray and composited into a single effluent sample. Stations were sampled only once during a sampling day because it was determined that more frequent sampling did not affect results.

• Feed System Maintenance

Feed tubing and the distribution manifolds required regular cleaning due to bacterial growths on the inside surface of the tubing. The feed tubing and distribution manifold were dismantled and brushed clean once per week. The interior of the feed tanks were rinsed daily with tap water and brushed clean with a chlorine solution once per week. Tubing in the feed pumps was changed once per week and the flow from each channel of the pumps was calibrated using a graduated cylinder and stop watch. Flow rates were checked and reset if necessary once per week.

• Cover Crop Harvest

The grass cover crop was mowed and harvested once per week. The grass was mowed to a constant height of about 8 cm using an apparatus consisting of 4 cordless-electric hand trimmers mounted on a horizontal pipe that was supported on either side by casters. Using this technique, the height of the grass was maintained between 8 and 15 cm approximately.

- Light Bank Operation

The artificial light banks were controlled by an on-off 24 hr time switch. The timer was set to provide a 14 hour on-period and a 10 hour off-period.

Synthetic Wastewater Studies Procedures

Synthetic wastewater was used to study the effects of slope grade application rate and hydraulic loading rate on overland flow treatment performance. Prior to starting any treatment studies, wastewater was applied to the beds under the same operating conditions to allow a slime layer to build up on the slopes. This slope acclimation was continued for about 2 months until the effluent quality from all three beds was consistent and equal.

- Wastewater Characteristics

The synthetic wastewater used in this study was prepared according to the following recipe:

sucrose - 174.4 mg/L

bactopeptone - 49.7 mg/L

NH_4 Cl - 69.4 mg/L

KH_2PO_4 - 21.8 mg/L

$K_2HPO_4 \cdot 3H_2O$ - 31.9 mg/L

The amounts of dry ingredients necessary to make up selected volumes of the wastewater were weighed out in advance and stored in sealed plastic bags. Wastewater batches were prepared just prior to application by mixing the pre-weighed dry ingredients with a known volume of tap water in the feed tanks. Tank contents were initially mixed by stirring with a paddle and were kept mixed with the recirculation pumps. Synthetic wastewater characteristics, as measured by analytical tests, are listed in Table 2. Because the wastewater was pumped through several feet of tubing prior to application, the characteristics of the wastewater discharged from the distribution manifold varied slightly from day to day.

- Slope Grade Study

A study to determine the effect of slope grade on removal of organics involved operating the beds at three different slope grades (2, 4, and 6

Table 2

Characteristics of Synthetic Wastewater

Constituent	Value, mg/L
BOD_5	135-145
TOC	90-100
Suspended Solids	0
Total N	23-25
NH_3-N	12-14
NO_3-N	0
Total-P	10
pH	7.5-8.0

percent) while holding all other operating parameters constant. The operating conditions used during the slope grade studies were as follows:

application rate - 26.2 mL/min•cm

application period - 6 hr/day

application frequency - 5 days/week

hydraulic loading rate - 3 cm/day/30m

It should be noted that the application rate used in these studies is in the range used at full-length overland flow systems. Thus, the 6.1 m experimental beds used in these pilot studies were intended to simulate the first 6.1 m of a longer overland flow slope. The resulting hydraulic loading rates computed on the basis of the 6.1 meter slope length were much higher than the rates normally associated with full-length systems. To allow the hydraulic loading rates used in this study to be more easily compared with rates used at existing full-length systems, the hydraulic loading rates used in this study were computed on the basis of a 30 m slope length and are expressed in units of cm/day/30m. The hydraulic loading rates based on the actual slope length of 6.1 meters would be roughly 5 times the rate computed on the basis of 30 m slope length.

Samples were taken as indicated in the general procedures except that additional samples were taken at the midpoints between Stations 0 and 1, 1 and 2, and 2 and 3. These stations were designated as 0.5, 1.5, and 2.5, respectively. The samples were analyzed for BOD_5 and TOC. The slope grade study was conducted for a period of 8 weeks.

- Application Rate Study

A study to determine the effect of application rate on removal of organics was conducted by operating the beds at three different application rates (13.1, 26.2, and 39.4 mL/min•cm) while holding the other parameters constant except application period. To maintain a constant hydraulic loading rate while varying the application rate, it is necessary to vary the application period as well. The resulting application periods associated with the different application rates were approximately 12, 6, and 4 hours/day, respectively. The other operating conditions used in this study were as follows:

hydraulic loading rate - 3 cm/day/30m

application frequency - 5 days/week

slope grade - 4 percent

Samples were taken as described in the general procedures and were analyzed for BOD_5 and TOC. The application rate study was conducted for a period of five weeks.

- Hydraulic Loading Rate Study

A study to determine the effect of hydraulic loading rate on removal of organics was conducted by operating the beds at three different hydraulic loading rates (2, 3, and 6 cm/day/30m) while holding the other parameters constant except application period. To maintain a constant application rate while varying the hydraulic loading rate, it is necessary to vary the application period as well. The resulting application periods associated with the different hydraulic loading rates were approximately 4, 6, and 12 hours/day. The other operating parameters used in this study were as follows:

application rate - 26.2 mL/min•cm

application frequency - 5 days/week

slope grade - 4 percent

Samples were taken as indicated in the general procedures and were analyzed for BOD_5 and TOC. The hydraulic loading rate study was conducted for a period of 4 weeks.

Primary Effluent Studies Procedures

Studies comparable to the synthetic wastewater studies and other treatment studies were conducted using primary effluent from the City of Davis wastewater treatment plant and the U.C. Davis wastewater treatment plant. Prior to starting treatment studies with primary effluent, primary effluent was applied to the beds under the same operating conditions to acclimate the slopes to the change in wastewaters. Approximately one month of acclimation was required to produce a consistent effluent from all three beds. A considerable amount of unloading of the slime layer that was built up during the synthetic wastewater studies occurred during the initial stages of acclimation. This would indicate a significant change in the nature of the bacterial population on the slopes.

- Wastewater Characteristics

Primary effluent from the City of Davis wastewater treatment plant was used for all studies except the continuous application study. Primary effluent from the U.C. Davis wastewater treatment plant was used for that study because severe flooding at the city plant caused the primary tanks to be taken out of service at the time of the experiment. In both cases, primary effluent was pumped from the effluent channel of the primary tanks into a 2,800 liter tank truck and transported daily to the pilot study facilities. At the laboratory, specified volumes of wastewater were metered into the feed tanks. Excess wastewater was drained to waste. All wastewater was applied on the same day it was transported. The characteristics of the primary effluent from the City of Davis Plant are indicated in Table 3.

Table 3

Characteristics of Primary Effluent

	Value, mg/L	
Constituent	City of Davis	U.C. Davis
BOD_5	65-100	65-100
TOC	40-60	30-45
TOD	200-250	100-170
Suspended Solids	80-90	66-33
Total N	28-32	18-24
Ammonia-N	20-24	12-16
NO_3- N	0	0
pH	7.5-8.0	7.5-8.0

- Slope Grade Study

The slope grade study was not conducted with primary effluent because slope grade did not appear to have a significant effect on treatment performance based on the results of the slope grade study with synthetic wastewater and on similar results reported by other researchers (7, 19).

- Application Rate Study

The application rate study with primary effluent was conducted in an identical manner to the application rate study with synthetic wastewater. The application rates used in the study were 13.1, 26.2, and 39.4 mL/min•cm. The corresponding application periods were 12, 6, and 4 hours/day, respectively. The other operating conditions used in this study were as follows:

hydraulic loading rate - 3 cm/day/30m

application frequency - 5 days/week

slope grade - 4 percent

Samples were taken as described in the general procedures and were analyzed for BOD_5, TOC, TOD, and suspended solids. The application rate study was conducted for a period of 8 weeks.

- Hydraulic Loading Rate Study

The hydraulic loading rate study with primary effluent was conducted by operating the beds at three different hydraulic loading rates (2, 3, and 6 cm/day) while holding the other operating parameters except application period constant. The application periods corresponding to the above hydraulic loading rates were 4, 6, and 12 hours/day respectively. The other operating conditions used in this study were as follows:

application rate - 26.2 mL/min•cm

application frequency - 5 days/week

slope grade - 4 percent

Samples were taken as indicated in the general procedures and were analyzed for BOD_5, TOC, TOD, and suspended solids. The study was conducted for a period of 5 weeks.

- Extended Length Study

To determine the effect of longer down-slope travel distance on organic removal, a study was conducted by operating the three beds in series. Primary effluent was applied in the usual manner to Bed A. Effluent from Bed A was discharged into collection sump and pumped back to Feed Tank B. The water in Feed Tank B was then applied to Bed B in the usual manner and at the same rate used for application to Bed A. Effluent from Bed B was transferred to Feed Tank C and applied to Bed C in the manner just described. Effluent from Bed C was drained to waste in the usual manner. By operating the beds in series in the above manner, a total slope length of 18.3 m was achieved. The operating conditions used in this study were as follows:

application rate - 26.2 mL/min•cm
hydraulic loading rate - 3 cm/day/30m
application period - 6 hours/day
application frequency - 5 days/week
slope grade - 4 percent

Samples were taken in the usual manner from Bed A but only from the effluent trays (Station 5) of Beds B and C. Samples were analyzed for BOD$_5$, TOC, TOD, and suspended solids. The study was conducted for a period of 6 weeks.

- Continuous Application Study

A study to determine the effect of continuous application on organic removal was conducted by operating the three beds in series as described for the extended length study and applying wastewater continuously. As mentioned previously, primary effluent from the U.C. Davis wastewater treatment plant was used in this study only. The operating conditions used in this study were as follows:

application rate - 26.2 mL/min•cm
hydraulic loading rate - 11.8 cm/day
application period - 24 hours/day
application frequency - 7 days/week

Samples were taken and analyzed in the same manner as in the extended length study. The study was conducted for a period of 3 weeks.

- Effluent Characteristic Study Procedure

It was of interest to investigate the nature of the organic material in the effluent from the overland flow slopes in terms of its degradability and the relative amounts in soluble and insoluble forms. Degradability was assessed by aerating for 24 hours the effluents from all the beds during the extended length study and analyzing them for TOC and TOD. The results were compared to values determined for the effluents prior to aeration. Soluble and insoluble fractions were assessed by filtering effluent samples from the extended length study and analyzing for TOC and TOD. Results were compared with unfiltered samples.

- Other Studies

Limited studies to determine the effect of evapotranspiration rate on process performance and to measure wastewater detention time on the overland flow slope were conducted and are reported in other publications (20, 21).

RESULTS

Results of the various treatment studies are presented in this section in graphical and summary form.

Synthetic Wastewater Studies

Studies to determine the effects of slope grade, application rate, and hydraulic loading rate on organic removal efficiency were conducted with synthetic wastewater. Only the results from the slope grade study are reported here. Results from the other synthetic wastewater studies are reported in another publication (21).

- Slope Grade Study

The fractions of organic material remaining in terms of BOD_5 and TOC are plotted on a semi-log scale as functions of down-slope travel distance in Figures 3 and 4, respectively, for the three slope grades studied (2, 4, and 6 percent). The data points shown are mean values of the fraction remaining and the lines shown are statistically determined lines of regression forced to pass through the point (0,1). A summary of the resulting regression equations and correlation coefficients is presented in Table 4.

The regression coefficients are the slopes of the regression lines and represent the rates of change with distance of the fraction of organic material remaining. The regression coefficients were tested for homogeneity, and no significant differences among regression coefficients were found at the 5 percent level for the TOC case. For the BOD case, a significant (5 percent level) difference was found between the coefficients for the 4 and 2 percent slope grades and between the 4 and 6 percent slope grades but not between the 2 and 6 percent slope grades. Based on this finding and the TOC results it appears that the difference in treatment performance found for the 4 percent slope grade was not associated with difference in slope grade. A probable source of variation was the inclusion of debris from the slime layer in some surface flow samples. At times it was difficult to obtain a clean sample from the surface flow stations, especially on Bed B, because debris was stirred up when taking the sample. Because the TOC samples were

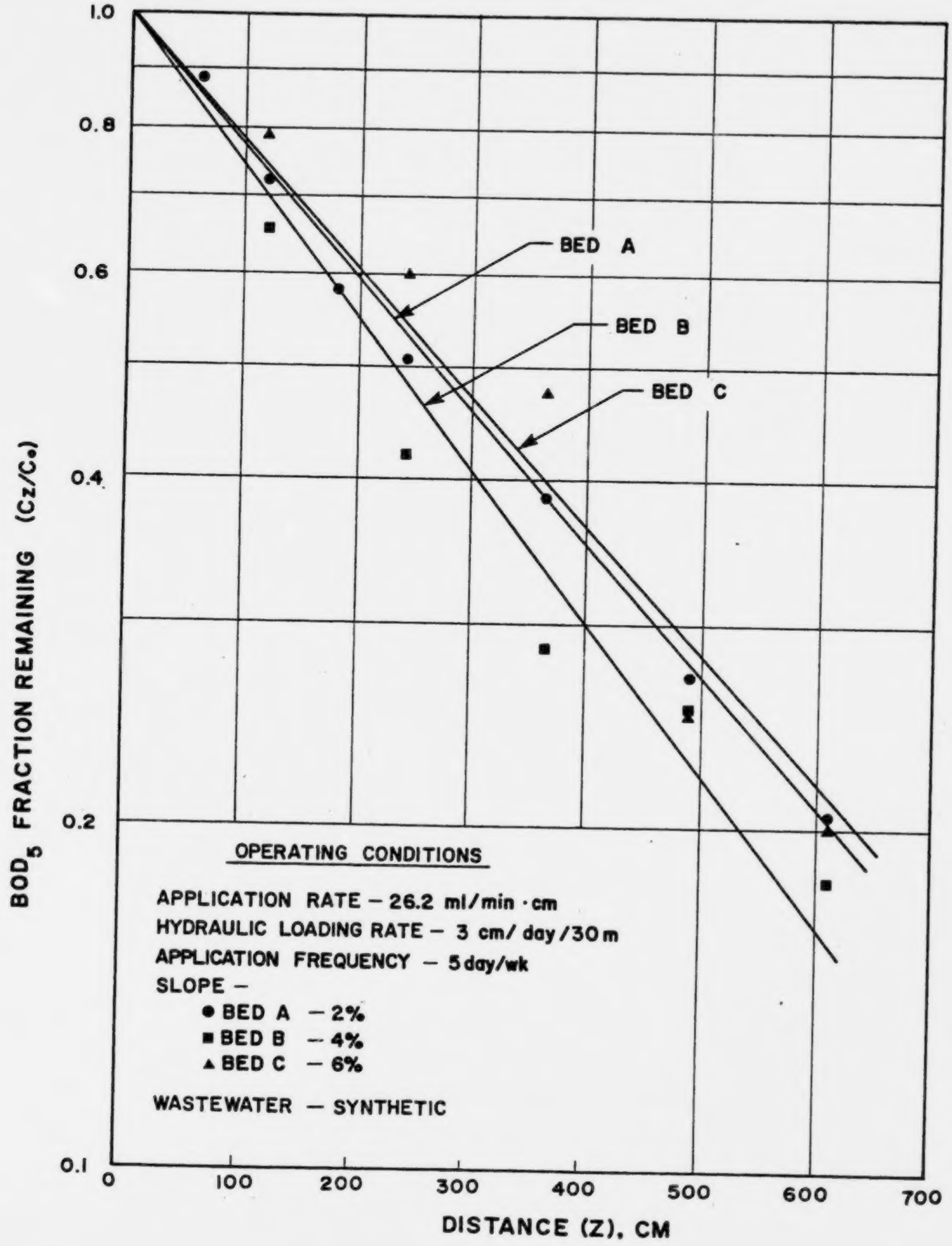

Figure 3. BOD$_5$ Fraction Remaining vs. Down-Slope Distance-Synthetic Wastewater Slope Grade Study.

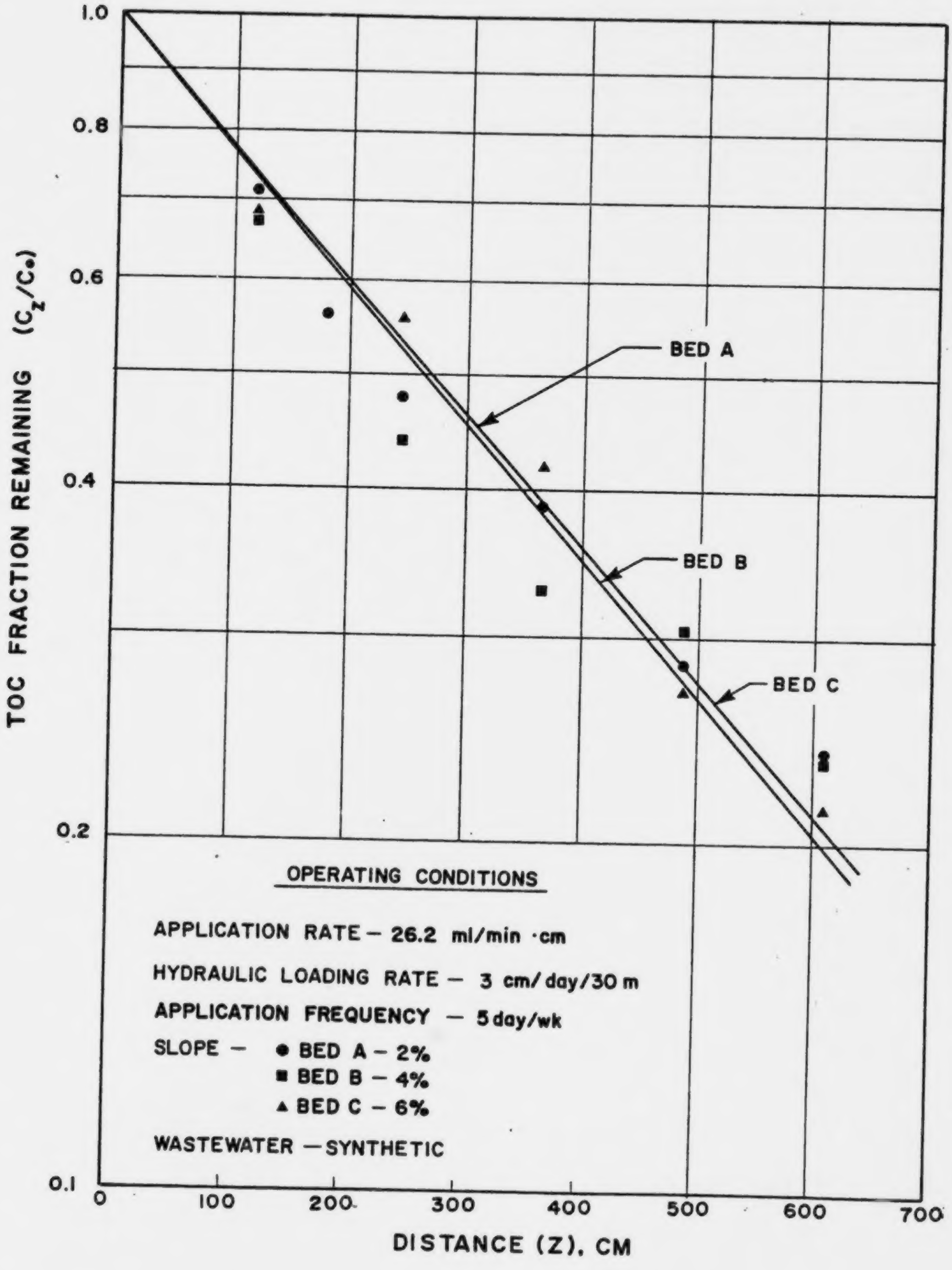

Figure 4. TOC Fraction Remaining vs. Down-Slope Distance-Synthetic Wastewater Slope Grade Study.

Table 4

Summary of Regression Parameters
For Synthetic Wastewater Slope Grade
Study

Measured Parameter	Slope Grade, %	Regression Coefficient	Regression Equation*	Correlation Coefficient, r
BOD_5	2	-0.00262	$C_z/C_o = e^{-0.00262(z)}$	0.977
	4	-0.00301	$C_z/C_o = e^{-0.00301(z)}$	0.982
	6	-0.00256	$C_z/C_o = e^{-0.00256(z)}$	0.986
TOC	2	-0.00259	$C_z/C_o = e^{-0.00259(z)}$	0.973
	4	-0.00264	$C_z/C_o = e^{-0.00264(z)}$	0.973
	6	-0.00258	$C_z/C_o = e^{-0.00258(z)}$	0.987

* z in centimeters

filtered, any effects due to debris would be eliminated. As indicated above, no difference in treatment perfomance due to slope grade was detected on the basis of TOC removal. On the basis of the results presented above and similar findings reported from studies at Pauls Valley, OK (19) and Utica, MS (7), it was concluded that slope grade in the range of 2 to 6 percent should not be included as a parameter in an overland flow organic removal model. Consequently, a slope grade study was not conducted with primary effluent.

Primary Effluent Studies

Studies comparable to the synthetic wastewater studies plus studies to determine the effects of longer travel distance and continuous application on organic removal efficiency were conducted with primary effluent. Results from each study are presented below.

- Application Rate Study

The primary effluent application rate study was conducted using three different application rates (13.1, 26.2, and 39.4 mL/min•cm). The results are presented in the form of semi-log plots of BOD_5, TOC, and TOD fraction remaining versus travel distance down the slope and are shown in Figures 5, 6, and 7, respectively. The data points shown represent mean values of the fraction remaining and the lines are regression lines forced to pass through the point (0,1) including influent concentrations. A summary of regression coefficients and equations and correlation coefficients are presented in Table 5. The average concentration of suspended solids in the effluent from each bed is presented in Table 6.

On the basis of the preliminary organic removal models developed earlier the expected relationship between application rate (q) and organic removal efficiency is that given by equation 11.

$$\frac{C_z}{C_o} = \exp\left(-\frac{Kz}{q^n}\right) \qquad \text{(Equation 11)}$$

The form of this relationship is strongly supported by the results of the primary effluent application rate study. Using graphical techniques described in another publication (21) values were determined for the exponent n and the rate constant K that appear in equation 11. For the BOD case the values of n and K are 0.48 and 6.78×10^{-3} cm/min, respectively. For the TOC case the corresponding values are 0.42 and 5.39×10^{-3}, respectively. Substituting these values into the model (Equation 11) yields the following predictive relationships for the removal of BOD_5 and TOC from primary effluent.

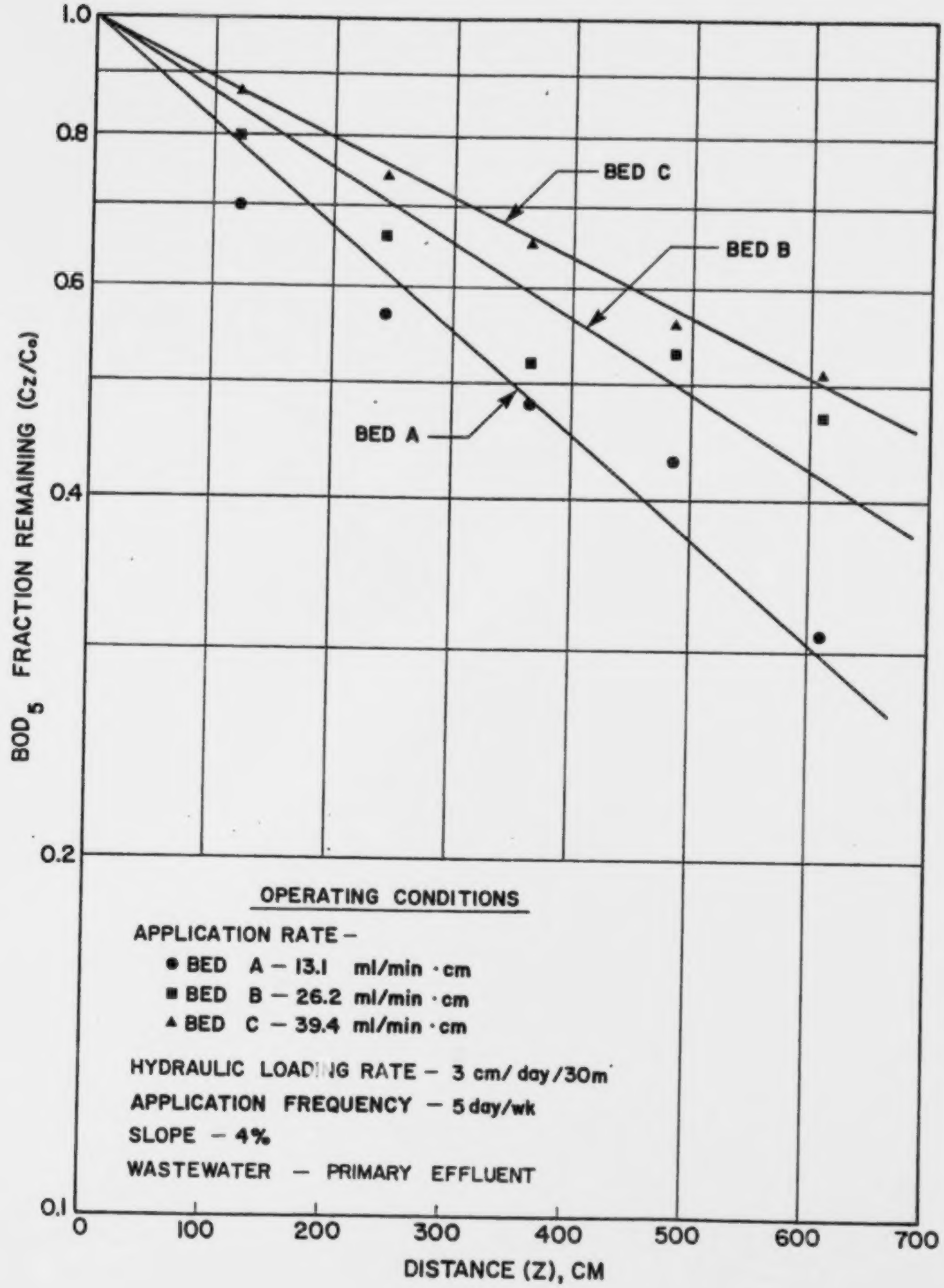

Figure 5. BOD_5 Fraction Remaining vs. Down-Slope Distance-Primary Effluent Application Rate Study.

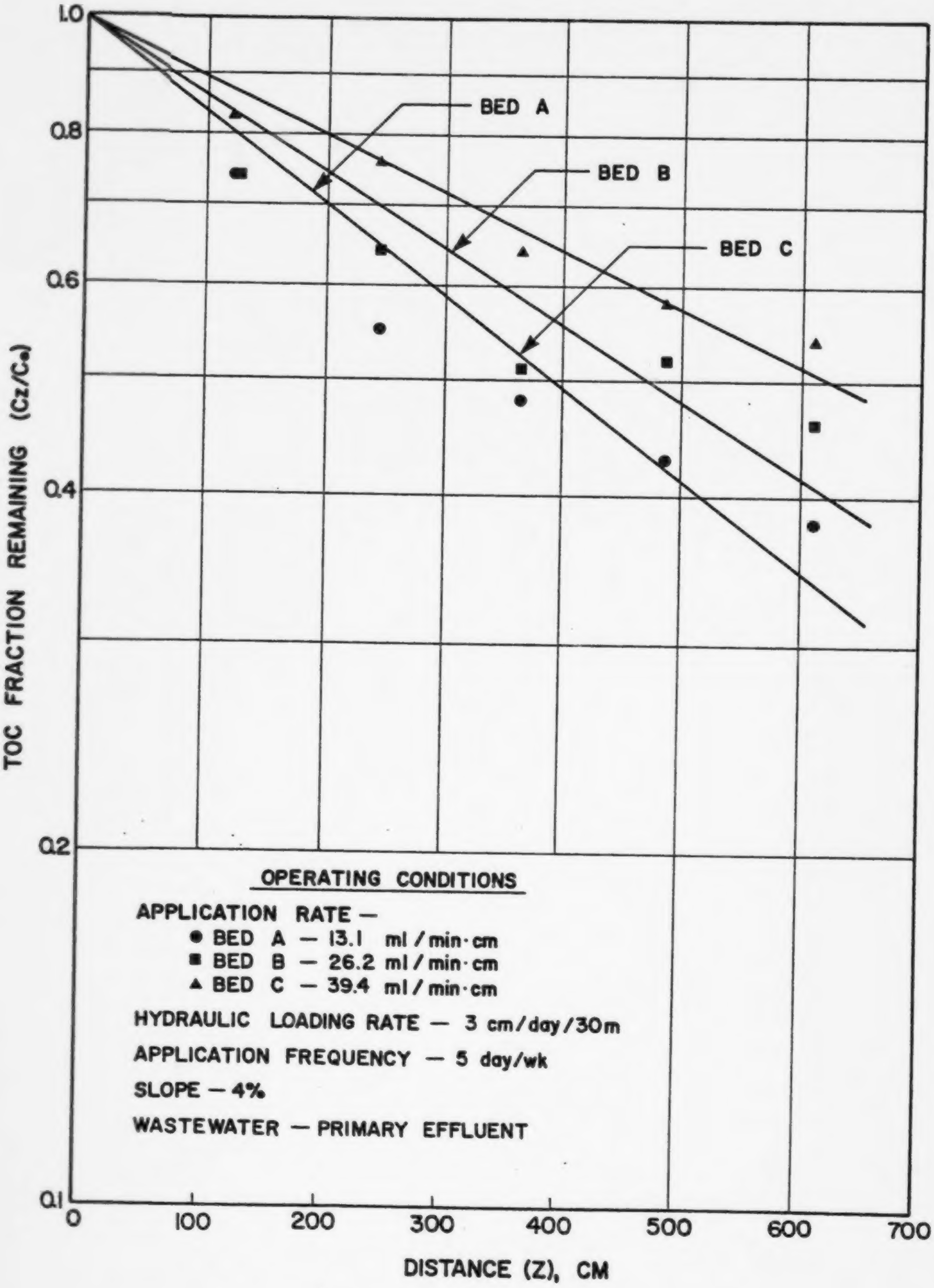

Figure 6. TOC Fraction Remaining vs. Down-Slope Distance-Primary Effluent Application Rate Study.

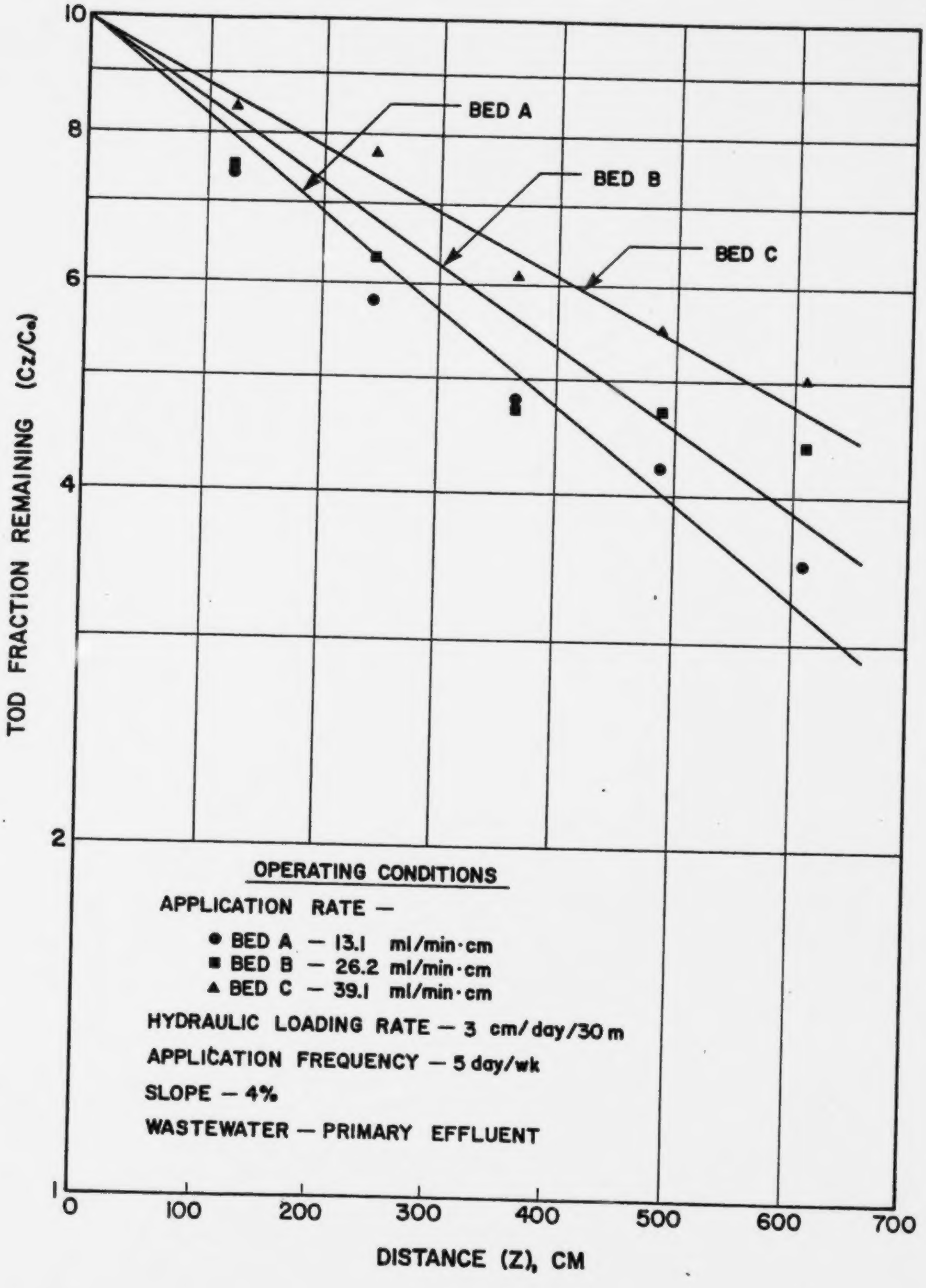

Figure 7. TOD Fraction Remaining vs. Down-Slope Distance-Primary Effluent Application Rate Study.

Table 5

Summary of Regression Parameters
For Primary Effluent Application
Rate Study

Measured Parameter	Application Rate, mL/min•cm	Regression Coefficient	Regression Equation*	Correlation Coefficient, r
BOD_5	13.1	-0.00197	$C_z/C_o = e^{-0.00197(z)}$	0.971
	26.2	-0.00142	$C_z/C_o = e^{-0.00142(z)}$	0.968
	39.4	-0.00116	$C_z/C_o = e^{-0.00116(z)}$	0.983
TOC	13.1	-0.00178	$C_z/C_o = e^{-0.00178(z)}$	0.983
	26.2	-0.00147	$C_z/C_o = e^{-0.00147(z)}$	0.957
	39.4	-0.00110	$C_z/C_o = e^{-0.00110(z)}$	0.969
TOD	13.1	-0.00185	$C_z/C_o = e^{-0.00185(z)}$	0.989
	26.2	-0.00160	$C_z/C_o = e^{-0.00160(z)}$	0.973
	39.4	-0.00123	$C_z/C_o = e^{-0.00123(z)}$	0.961

* z in centimeters

Table 6

Summary of Average Effluent
Suspended Solids Concentrations
Measured During Primary Effluent Studies

Parameter Studied	Parameter Units	Parameter Value	Effluent Suspended Solids, mg/L
Application Rate	mL/min•cm	13.1	14.2
		26.2	24.7
		39.4	25.9
Hydraulic Loading Rate	cm/day/30m	2.0	27.0
		3.0	25.0
		6.0	30.0
Extended Length-Distance	meters	6.1	26.8
		12.2	25.0
		18.3	17.0
Continuous Application-Distance	meters	6.1	6.8
		12.2	12.7
		18.3	15.8

BOD Removal Model

$$\frac{C_z}{C_o} = \exp\left[-\frac{6.78 \times 10^{-3}\,(z)}{q^{0.48}}\right] \qquad \text{(Equation 20)}$$

TOC Removal Model

$$\frac{C_z}{C_o} = \exp\left[-\frac{5.39 \times 10^{-3}\,(z)}{q^{0.42}}\right] \qquad \text{(Equation 21)}$$

These equations are valid for q in the range of 13.1 to 39.4 mL/min•cm and for z in the range of 0 to 600 cm.

A model similar to those developed for BOD and TOC removal could be developed from the TOD data. However, because the TOD test measures nitrogenous as well as carbonaceous oxygen demand, the TOD value is dependent on the level and chemical form of nitrogen present. Consequently, a model describing the removal of TOD would have to include the parameters that affect nitrogen removal and transformation during overland flow treatment. As indicated in studies by Wright (5) nitrogen transformation appears to be affected by a number of factors in addition to application rate including temperature, hydraulic loading rate, and/or application period. Thus, the development of a model to predict TOD removal is considerably more complicated than TOC or BOD removal models. Such a model will have to be developed in conjunction with a nitrogen removal model.

- Hydraulic Loading Rate Study

The primary effluent hydraulic loading rate study was conducted using three hydraulic loading rates (2, 3, and 6 cm/day). Semi-log plots of BOD_5, TOC, and TOD fraction remaining versus travel distance down the slope are shown in Figures 8, 9, and 10, respectively. The data points shown are mean values and the lines are regression lines forced to pass through the point (0,1). A summary of regression coefficients and equations and correlation coefficients is presented in Table 7. Effluent suspended solids data are shown in Table 6.

In contrast to the results of the synthetic wastewater hydraulic loading rate study, changes in hydraulic loading rate of primary effluent had little or no effect on treatment performance in terms of BOD and TOC removal. In both the BOD and TOC case no significant differences at the 5 percent level were found between the regression coefficients associated with the 6 and 3 cm/day loading rates. The regression coefficients for the 2 cm/day loading rate were found to be significantly different statistically at the 1 percent level from the coefficients for the other rates, but the differences are

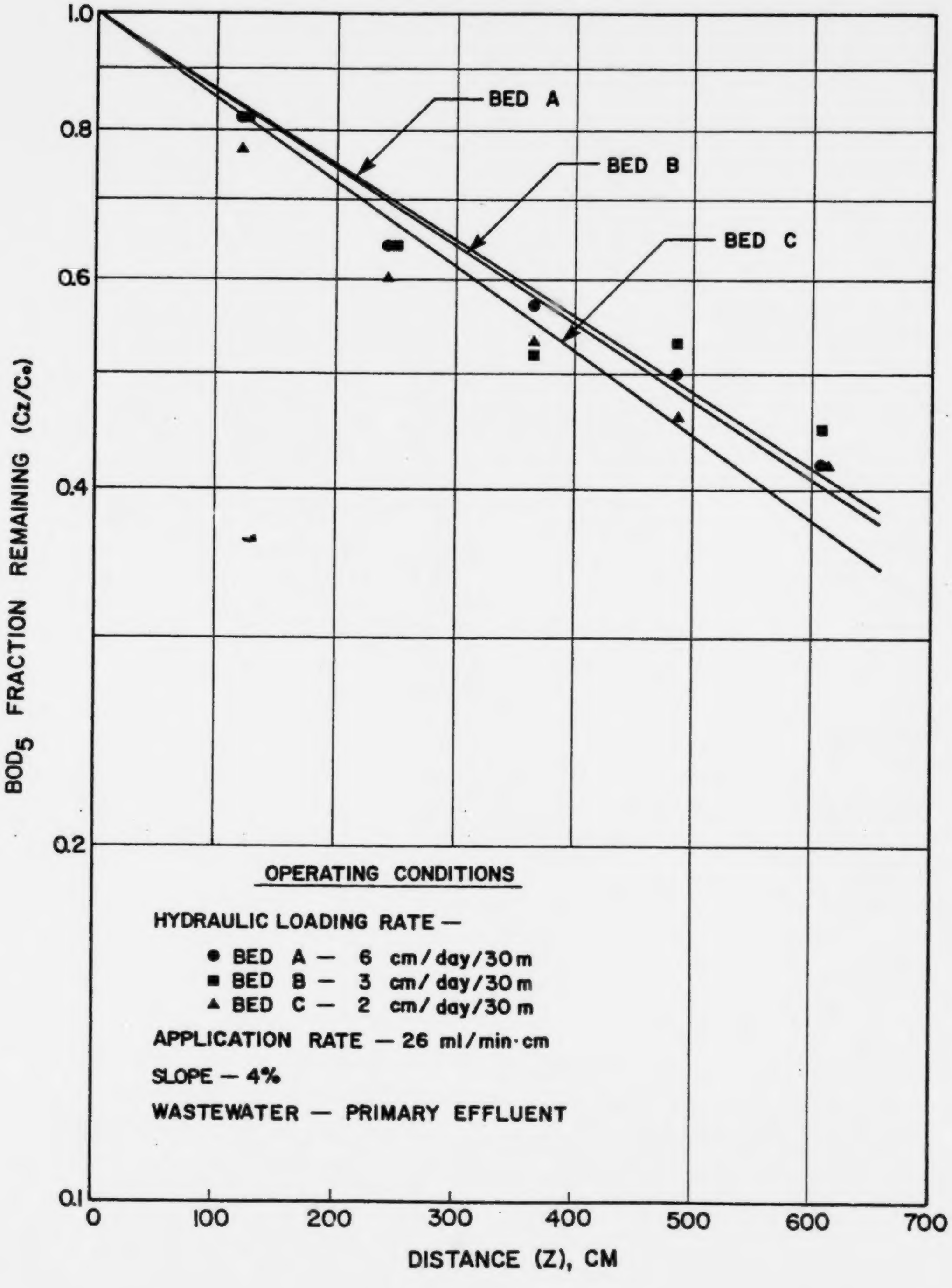

Figure 8. BOD5 Fraction Remaining vs. Down-Slope Distance-Primary Effluent Hydraulic Rate Loading Study.

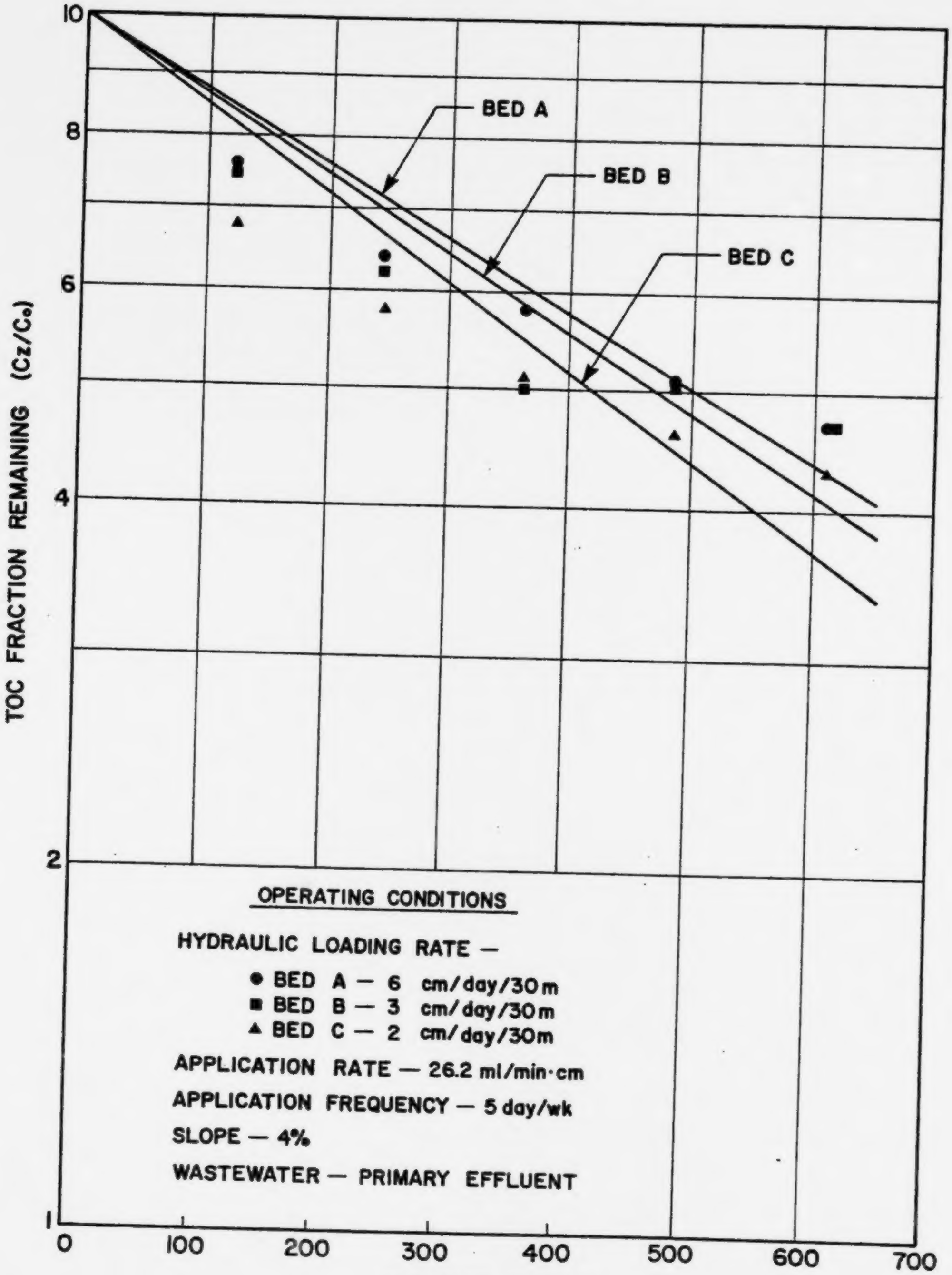

Figure 9. TOC Fraction Remaining vs. Down-Slope Distance-Primary Effluent Hydraulic Loading Rate Study.

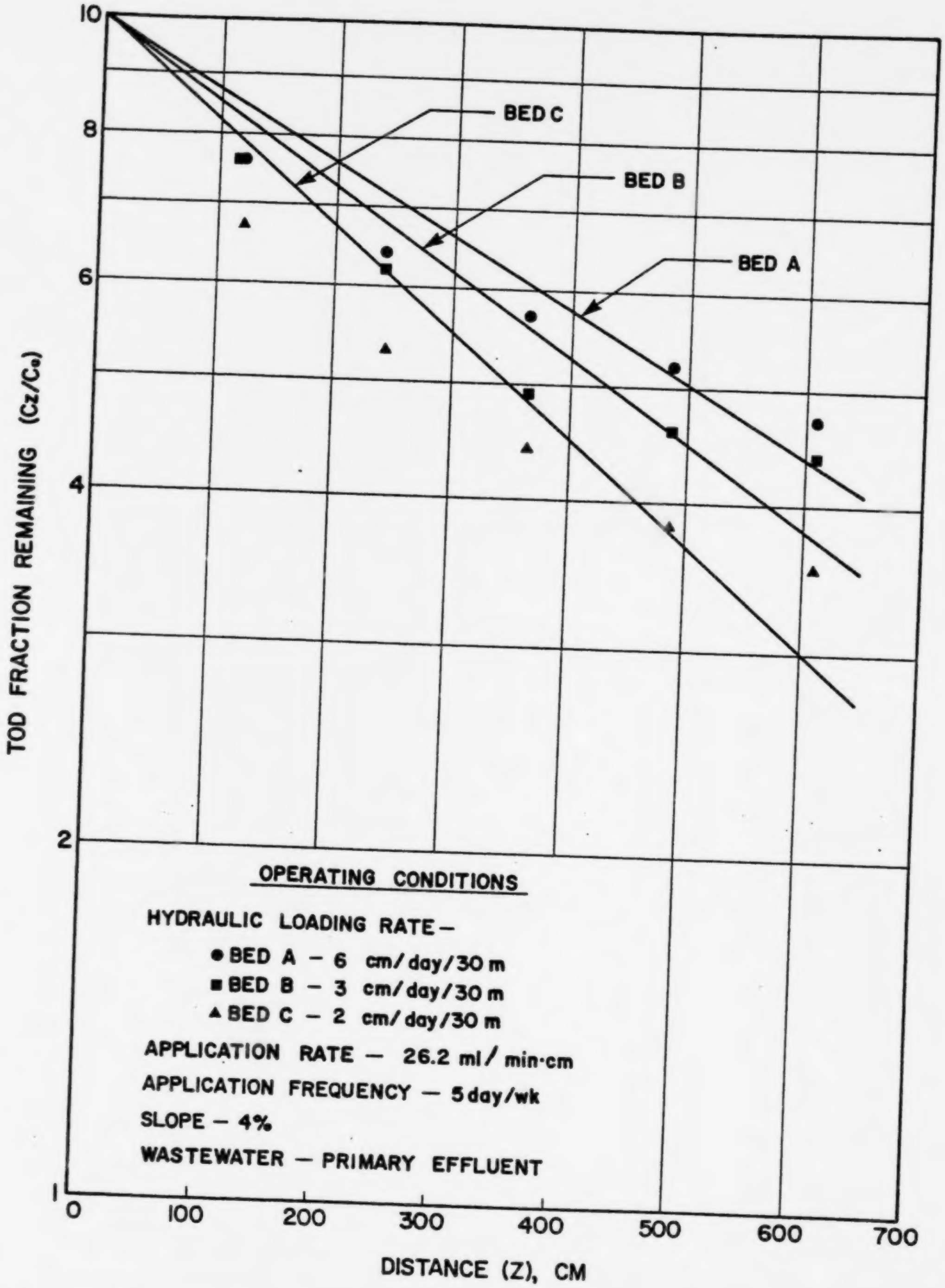

Figure 10. TOD Fraction Remaining vs. Down-Slope Distance-Primary Effluent Hydraulic Loading Rate Study.

Table 7

Summary of Regression Parameters For Primary Effluent Hydraulic Loading Rate Study

Measured Parameter	Hydraulic Loading, cm/day/30m	Regression Coefficient	Regression Equation*	Correlation Coefficient, r
BOD_5	2	-0.00158	$C_z/C_o = e^{-0.00158(z)}$	0.987
	3	-0.00142	$C_z/C_o = e^{-0.00142(z)}$	0.982
	6	-0.00147	$C_z/C_o = e^{-0.00147(z)}$	0.984
TOC	2	-0.00162	$C_z/C_o = e^{-0.00162(z)}$	0.962
	3	-0.00146	$C_z/C_o = e^{-0.00146(z)}$	0.962
	6	-0.00140	$C_z/C_o = e^{-0.00140(z)}$	0.968
TOD	2	-0.00198	$C_z/C_o = e^{-0.00198(z)}$	0.966
	3	-0.00159	$C_z/C_o = e^{-0.00159(z)}$	0.973
	6	-0.00138	$C_z/C_o = e^{-0.00138(z)}$	0.964

* z in centimeters

small and would be considered insignificant from the standpoint of practical process control. Consistent and significant differences in TOD removal rates were observed however. The differences are attributed to the decrease in the rate of TKN removal associated with increasing hydraulic loading rate and/or application period as reported by Wright (5).

- Extended Length Study

The effect of longer travel distances down-slope on organic removal was studied by operating the beds in series so as to simulate an effective down-slope travel distance of 18.3 m. A semi-log plot of BOD_5 and TOC remaining versus travel distance down the slope is shown in Figure 11. Similar results for TOD values are presented in Figure 12. The data points shown are mean values and the lines are regression lines forced to pass through the point (0,1). The regression coefficients and equations and the correlation coefficients for the regression lines shown in Figures 10 and 11 are summarized in Table 8. Effluent suspended solids data are shown in Table 6.

It can be seen from the data points shown in Figure 11 that the rate of organic removal observed over the first few meters of travel is significantly greater than the removal rate observed over the remaining length of slope. Considering this observed difference in removal rates over different portions of the slope, a more appropriate description of removal of organic material from primary effluent by overland flow would be a two-stage or composite model. The first stage of the model would apply over the first few meters of the slope and the second stage would apply over the remainder of the slope. Such models for BOD and TOC removal are illustrated in Figures 13 and 14, respectively, with data from the extended length study. The first stage of the model is of the same general form as the models described previously (Equation 11).

$$\frac{C_z}{C_o} = \exp\left(- \frac{Kz}{q^n}\right)$$

Values for the coefficients, K and n, for both BOD and TOC removal models were determined as part of the primary effluent application rate study and are indicated in equations 20 and 21, respectively.

The second stage of the composite model is of the form

$$\frac{C_z}{C_o} = A \exp\left(- \frac{K'z}{q^{n'}}\right) \qquad \text{(Equation 21)}$$

The coefficient A is the value of C_z/C_o where the second-stage regression line intersects the vertical axis as indicated in Figures 13 and 14. Because

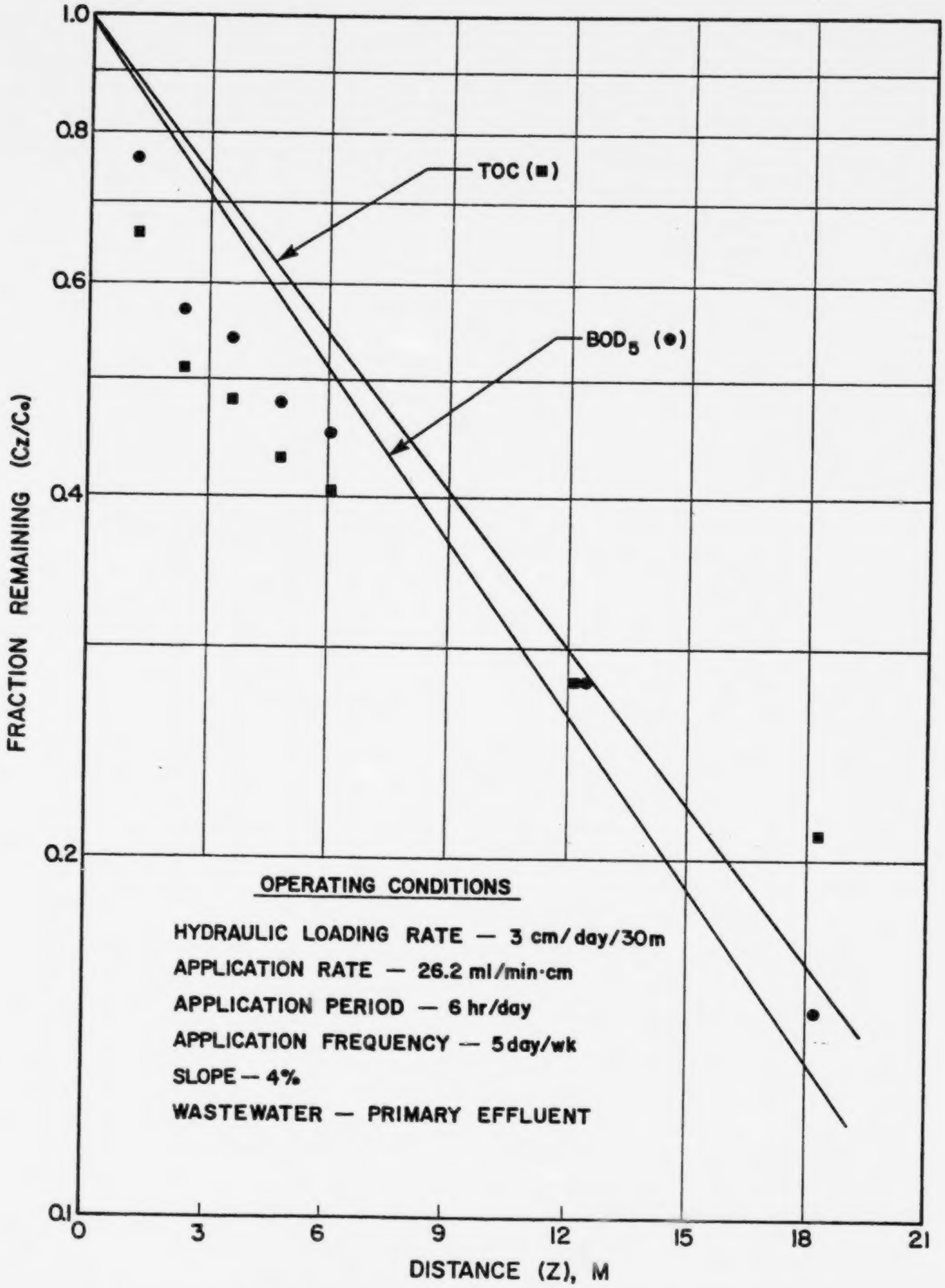

Figure 11. Organic Fraction Remaining vs. Down-Slope Distance-Primary Effluent Extended Length Study.

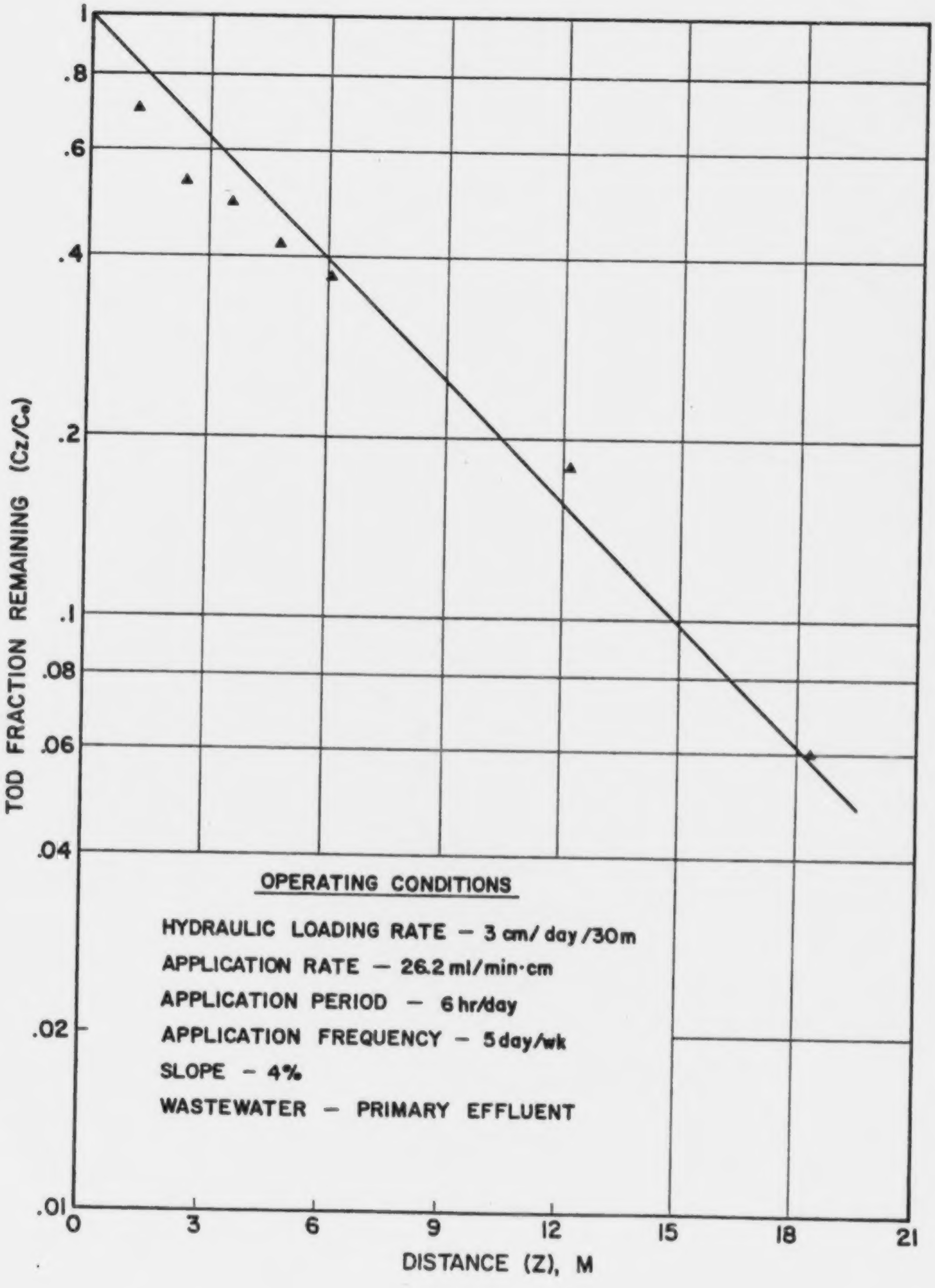

Figure 12. TOD Fraction Remaining vs. Down-Slope Distance-Primary Effluent Extended Length Study.

Table 8

Summary of Regression Parameters For Primary Effluent Extended Length Study

Measured Parameter	Regression Coefficient	Regression Equation*	Correlation Coefficient, r
BOD_5	-0.00110	$C_z/C_o = e^{-0.00110(z)}$	0.980
TOC	-0.00101	$C_z/C_o = e^{-0.00101(z)}$	0.953
TOD	-0.00155	$C_z/C_o = e^{-0.00155(z)}$	0.900

* z in centimeters

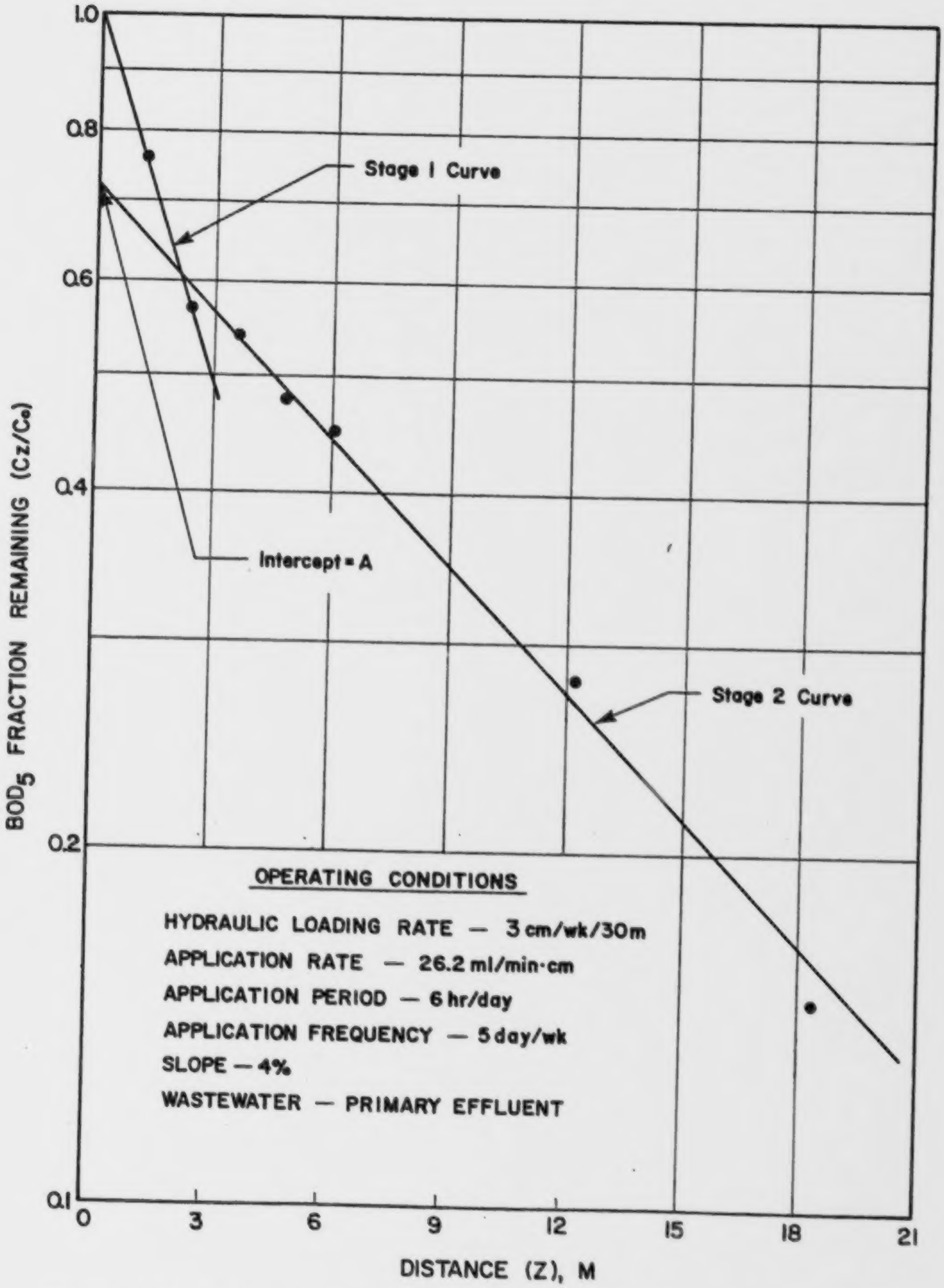

Figure 13. BOD_5 Fraction Remaining vs. Down-Slope Distance-Two-Stage BOD Removal Model.

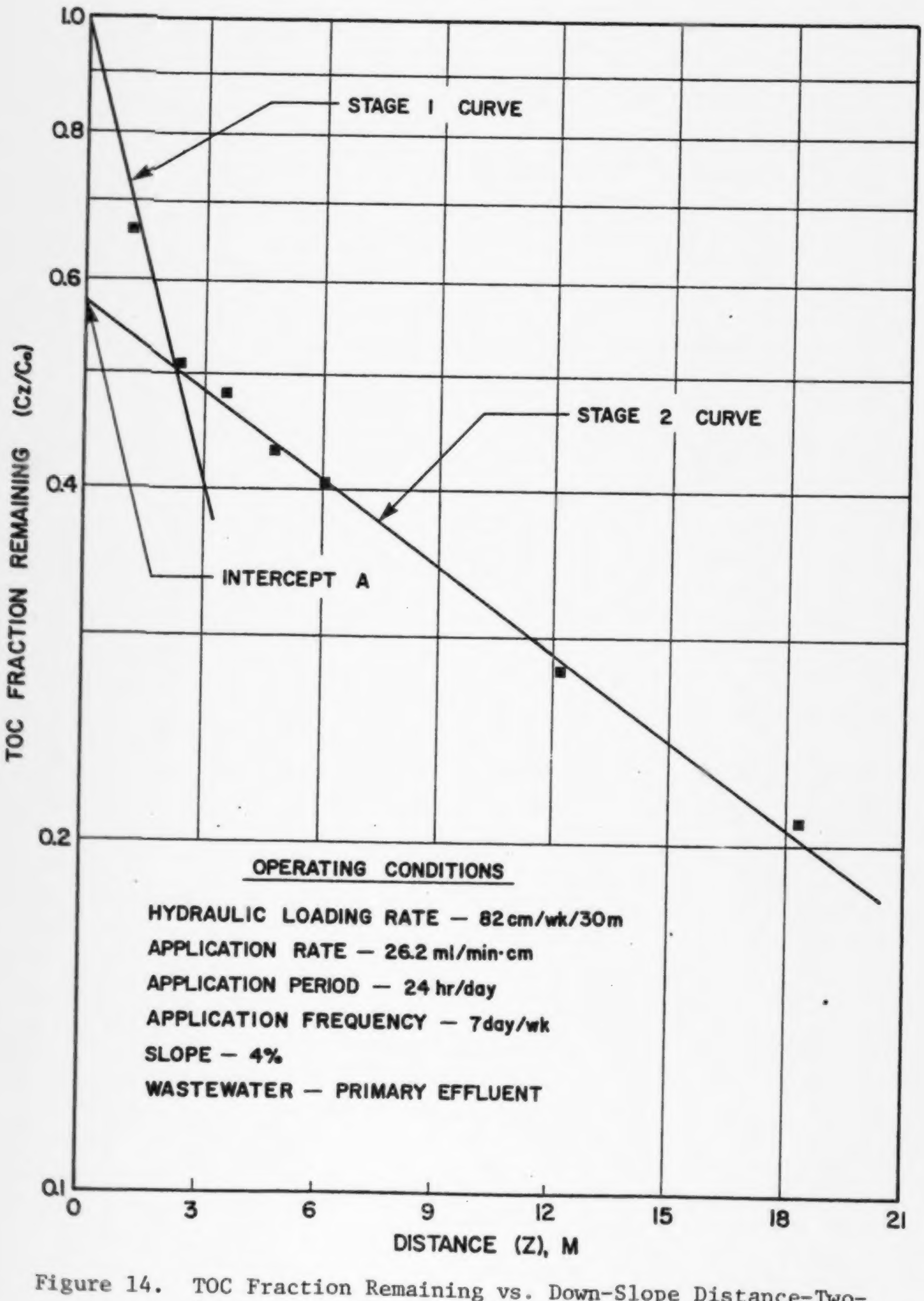

Figure 14. TOC Fraction Remaining vs. Down-Slope Distance-Two-Stage TOC Removal Model.

the extended length study was conducted at a single application rate, values for the coefficients K and n could not be determined from the available data. To generate the data necessary to determine values for these coefficients, full-length overland flow slopes must be operated in parallel slopes at several different application rates. Such studies are planned as part of the Phase II field studies. Regression equations for the Stage 2 curves shown in Figures 13 and 14 can be written. However, the equations are applicable only under the operating conditions indicated on the respective figures. The Stage 2 regression equation for BOD removal is

$$\frac{C_z}{C_o} = 0.72 \exp \left[-8.1 \times 10^{-4} (z)\right] \qquad \text{(Equation 23)}$$

where z = slope length, cm

The Stage 2 regression equation for TOC removal is

$$\frac{C_z}{C_o} = 0.58 \exp \left[-5.64 \times 10^{-4} (z)\right] \qquad \text{(Equation 24)}$$

where z = slope length, cm

To confirm the validity of the two-stage model concept, a test was conducted on a full-length slope at the overland flow research facility operated by the U.S. Army Corps of Engineers' Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, N.H. The test consisted of taking grab samples of surface flow from two parallel slopes at several locations down the length of each slope. The samples were collected and analyzed by CRREL personnel and reported to U.C. Davis. The results obtained from the two slopes were averaged and are summarized in Table 9. The operating conditions used during the test also are indicated in Table 9.

A graphical comparison of the BOD results from the CRREL test with the results of the extended length study is presented in Figure 15. The regression equation determined from the CRREL data is

$$\frac{C_z}{C_o} = 0.72 \exp \left[-5.6 \times 10^{-4} (z)\right] \qquad \text{(Equation 25)}$$

where z = slope length, cm

This equation is of the same general form as equation 23 from the extended length study. Both regression lines have the same intercept value but the regression coefficients (slopes) of the lines are different. The regression coefficients represent rate of organic removal. Possible reasons for the observed difference in organic removal rates include differences in the nature of the organics in the wastewaters, difference in the coverage of the cover crop and differences in wastewater temperature.

Table 9

Quality of Surface Runoff at Various
Distances Down-Slope - CRREL Test, June 12, 1980

Distance Down-slope, m	Measured Constituent									
	BOD_5		TOC-Unfiltered		TOC-Filtered		SS-Total		SS-Volatile	
	mg/L	C/C_o	mg/L	C/C_o	mg/L	C/C_o	mg/L	C/C_o	mg/L	C/C_o
0	72.0	1.0	62	1.0	26	1.0	77.0	1.0	62	1.0
3.8	43.5	0.60	37	0.60	22	0.85	20.0	0.26	18	0.29
7.6	32.0	0.44	32.5	0.52	22	0.85	11.0	0.14	10.5	0.17
15.3	22.5	0.31	30.5	0.49	20	0.77	8.5	0.11	8.0	0.13
22.9	15.0	0.21	23.0	0.37	16.5	0.63	7.5	0.10	6.5	0.10
30.5	8.5	0.12	20.5	0.33	17	0.65	4.5	0.06	4.5	0.07

Operating Conditions

Application rate - 2.07 L/min•m
Application period - 7 hr/day
Application frequency - 5 day/week
Wastewater - primary effluent
Wastewater temp - 15°C

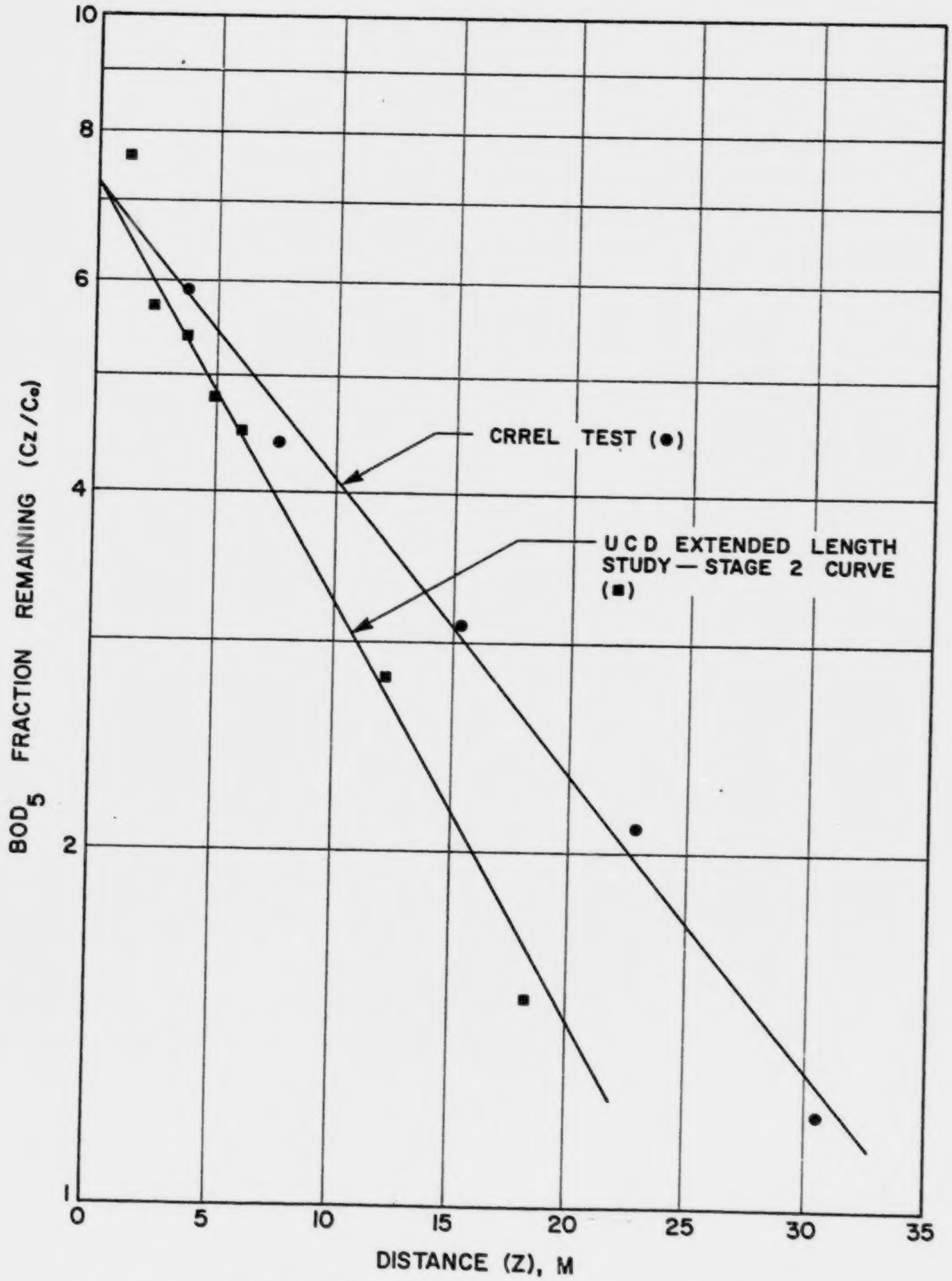

Figure 15. BOD5 Fraction Remaining vs. Down-Slope Distance-Comparison of CRREL Field Test and UCD Pilot Study Data.

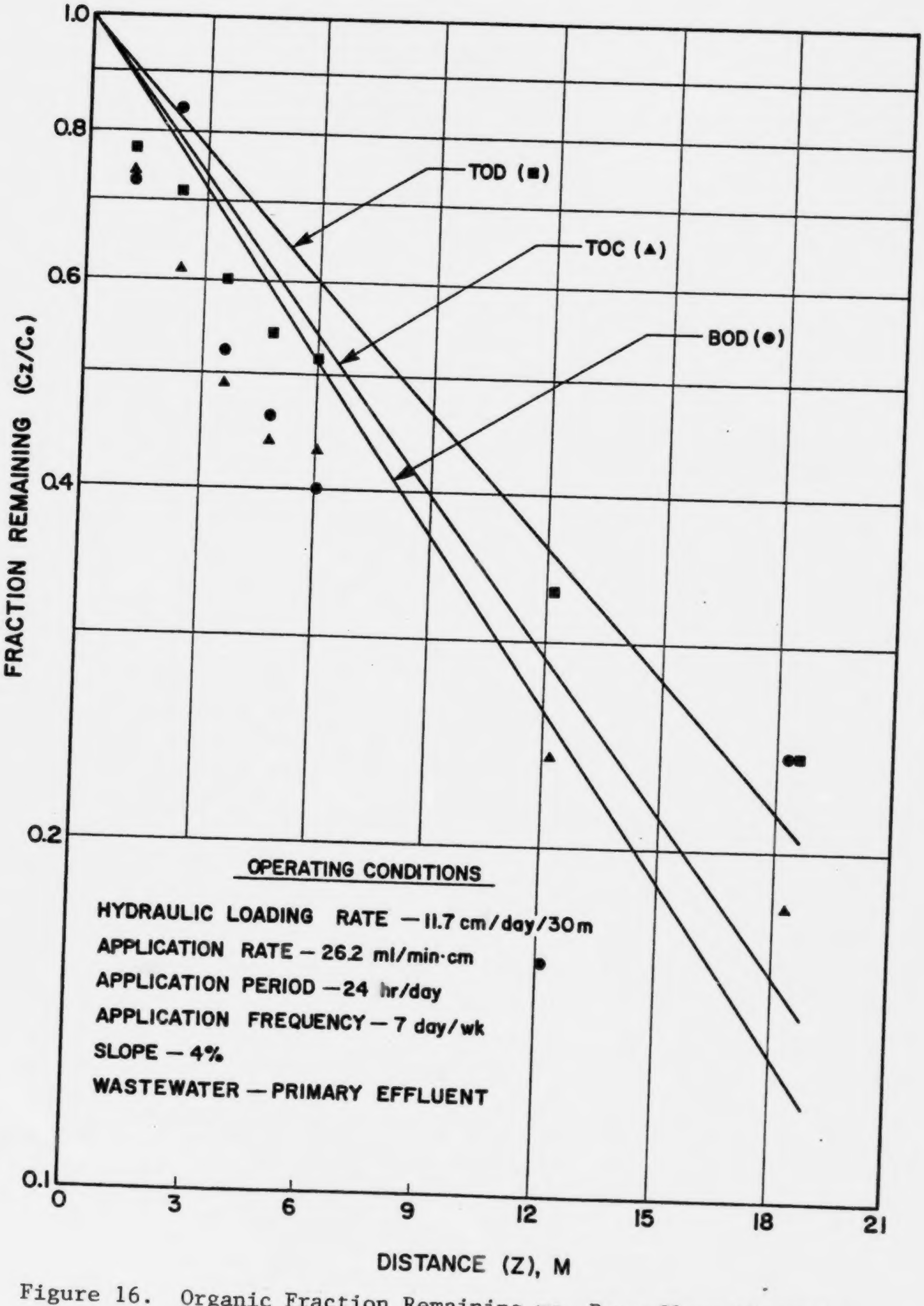

Figure 16. Organic Fraction Remaining vs. Down-Slope Distance Primary Effluent Continuous Application Study.

The observed rate of TOD removal in the extended length study is greater than the rates of BOD and TOC removal because of the conversion of TKN to nitrate nitrogen. The presence of nitrate nitrogen has the effect of reducing the measured TOD. All forms of nitrogen are converted to nitrous oxide (NO_2) gas during the TOD analysis. Upon conversion of NO_3 to NO_2, oxygen is produced, thus reducing the apparent oxygen demand of the sample.

- Continuous Application Study

The effect of continuous application on organic removal efficiency was studied by operating the beds in series in the same manner as during the extended length study except that application was continuous (i.e. 24 hrs/day). A semi-log plot of BOD_5 TOC, and TOD remaining versus travel distance down the slope is shown in Figure 16. The data points shown are mean values and the lines are regression lines forced to pass through the point (0,1). A summary of the regression parameters is presented in Table 10. Effluent suspended solids data are shown in Table 6.

The same pattern of organic removal was observed during the continuous application study as during the extended length study. A higher rate of removal occurred over the first few meters of travel than over the remaining length of slope.

It is apparent from the suspended solids data that sloughing of organic solids from Bed C was occurring as a result of the continuous application. This is reflected in a higher BOD concentration in the effluent from Bed C compared to Bed B and generally greater scatter in the data as indicated in Figure 14. However, the same response was not observed in the TOC case, in which effluent TOC concentration from Bed C was less than from Bed B. The fact that a higher TOC concentration in the effluent from Bed C was not observed can be attributed to the method of sample transfer. Sloughed solids in the effluent were large and settled rapidly. Samples for TOC analysis were removed from the original sample container with a syringe positioned at mid-depth in the jar. This technique apparently resulted in the exclusion of the large solids from the TOC sample.

In contrast to the extended length study, the rate of TOD removal was less than BOD and TOC removal. This result was due to the fact that, as reported by Wright (5), most of the nitrogen present during continuous application was in the ammonia or organic form, while during the extended length study (application period = 6 hr/day) most of the nitrogen was in the nitrate form. Nitrification apparently was inhibited under the condition of continuous application. A comparison of the distribution of nitrogen forms in the runoff during the two different application periods is shown in Figure 17. Also shown in the figure are relative nitrogen removal percentages. The amount of nitrogen removed by the cover crop was nearly constant throughout the pilot studies. The observed rate of crop removal was in range of 30 kg N/ha•month.

The effect of hydraulic loading rate on organic removal efficiency can be further evaluated by comparing the results of the extended length study with those of the continuous application study. In addition, the effects of

Table 10

Summary of Regression Parameters
for Primary Effluent Continuous
Application Study

Measured Parameter	Regression Coefficient	Regression Equation*	Correlation Coefficient, r
BOD_5	-0.00111	$C_z/C_o = e^{-0.00111(z)}$	0.925
TOC	-0.00106	$C_z/C_o = e^{-0.00106(z)}$	0.978
TOD	-0.00085	$C_z/C_o = e^{-0.00085(z)}$	0.987

* z in centimeters

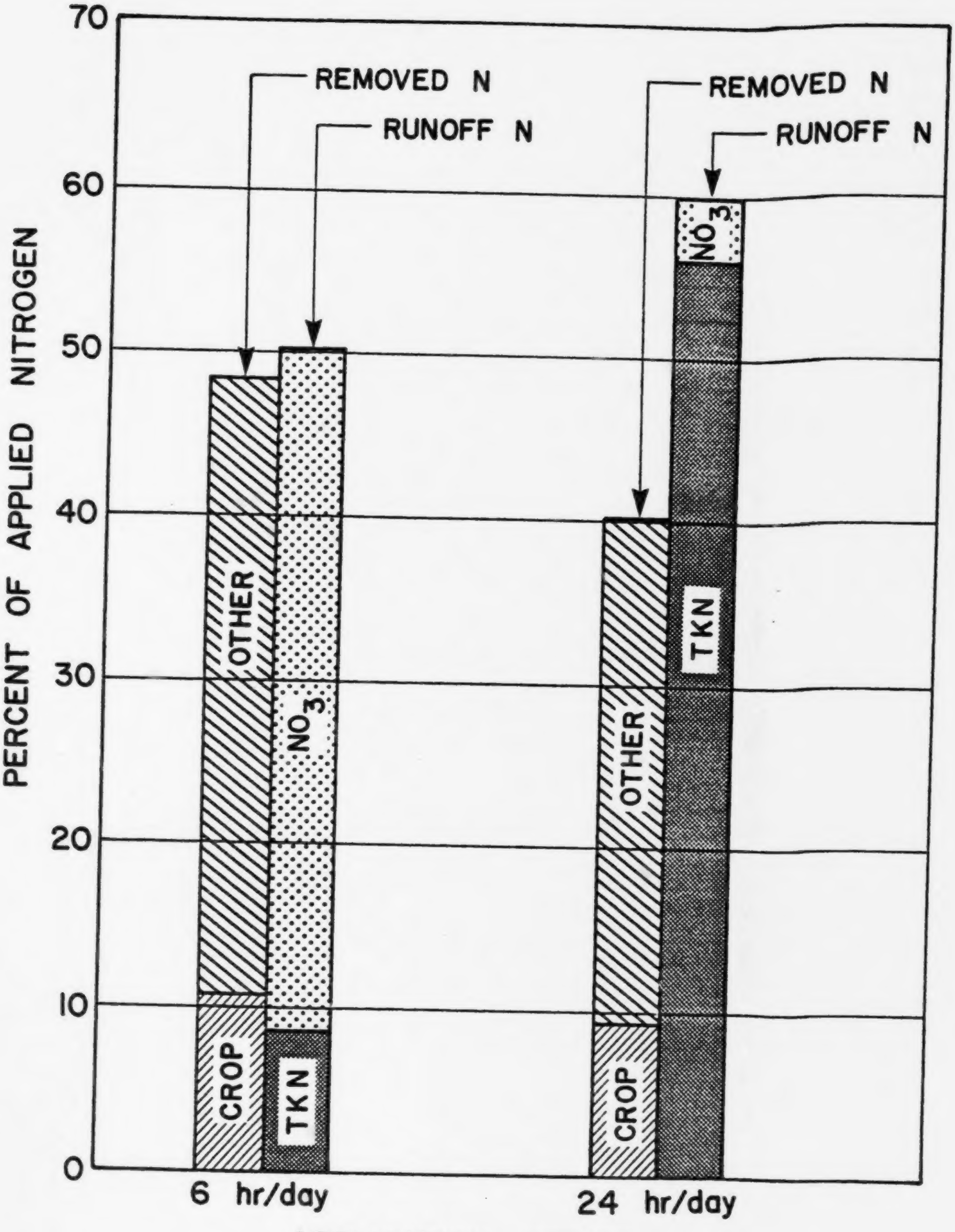

Figure 17. Comparison of Nitrogen Removal and Effluent Nitrogen Composition for Different Application Periods.

different sources of wastewater can be evaluated. The hydraulic loading rates used during the extended length study and the continuous application study were 3 cm/day and 11.7 cm/day, respectively. The application rate was the same during both studies, 26.2 mL/min•cm. The results obtained during both studies in terms of BOD, TOC, and TOD removal are compared graphically in Figures 18, 19, and 20, respectively. The BOD regression lines shown in Figure 18 are nearly identical for both hydraulic loading rates. The same comparison holds for the TOC regression lines in Figure 19. These results are in agreement with the results of the primary effluent hydraulic loading rate study in which it was demonstrated that hydraulic loading rate had little or no effect on organic removal efficiency. The TOD results differ substantially between the two studies due to the difference in the forms of nitrogen present as discussed previously.

- Temperature Effect

Although temperature was not a major parameter to be evaluated during these studies, the effect of temperature on organic removal was evaluated on a preliminary basis by observing changes in the rate of organic removal determined for Bed B in response to changes in the observed wastewater temperature. The operating conditions for Bed B remained the same throughout the pilot study. Thus, the only variables involved were the temperature and wastewater source. The rates of BOD removal in terms of the regression coefficients determined during each of the studies are listed in Table 11 along with the range of temperatures observed during each study. Because no consistent changes in regression coefficients were observed in response to changes in temperature, it can be concluded that the rate of organic removal was independent of temperature in the range of 18°-29°C. This finding is consistent with results from studies at Paris, Texas, reported by Thornthwaite (8) and at Hanover, New Hampshire, reported by Jenkins et al (22). In both cases temperature within the range of 16°-26°C was shown to have no significant effect on BOD removal efficiency. Thus, temperature need not be included as a model parameter when operating in that temperature range. However, as shown by Jenkins et al (22), temperature does become an important model parameter when the soil or wastewater temperature falls below about 10°C.

- Effluent Characteristic Study

It was of interest to determine the fractions of organic material in soluble and insoluble forms before and after treatment. Untreated primary effluent (Station 0) and slope runoff samples after 6.1 m, 12.2 m, and 18.3 m of down-slope travel were analyzed for TOC before and after filtration. The results are summarized in Table 12. It is apparent from these results that most of the filterable fraction of TOC is removed rapidly over the first 6.1 m and is almost completely removed after 18.3 m of travel. The non-filterable fraction, on the other hand, is reduced by only about 50 percent after 18.3 m of travel with most of the removal occurring in the first 6 m of travel. It is possible that the relatively slow rate of removal of non-filterable material was due to solublization of filterable organic material that was previously deposited on the slope.

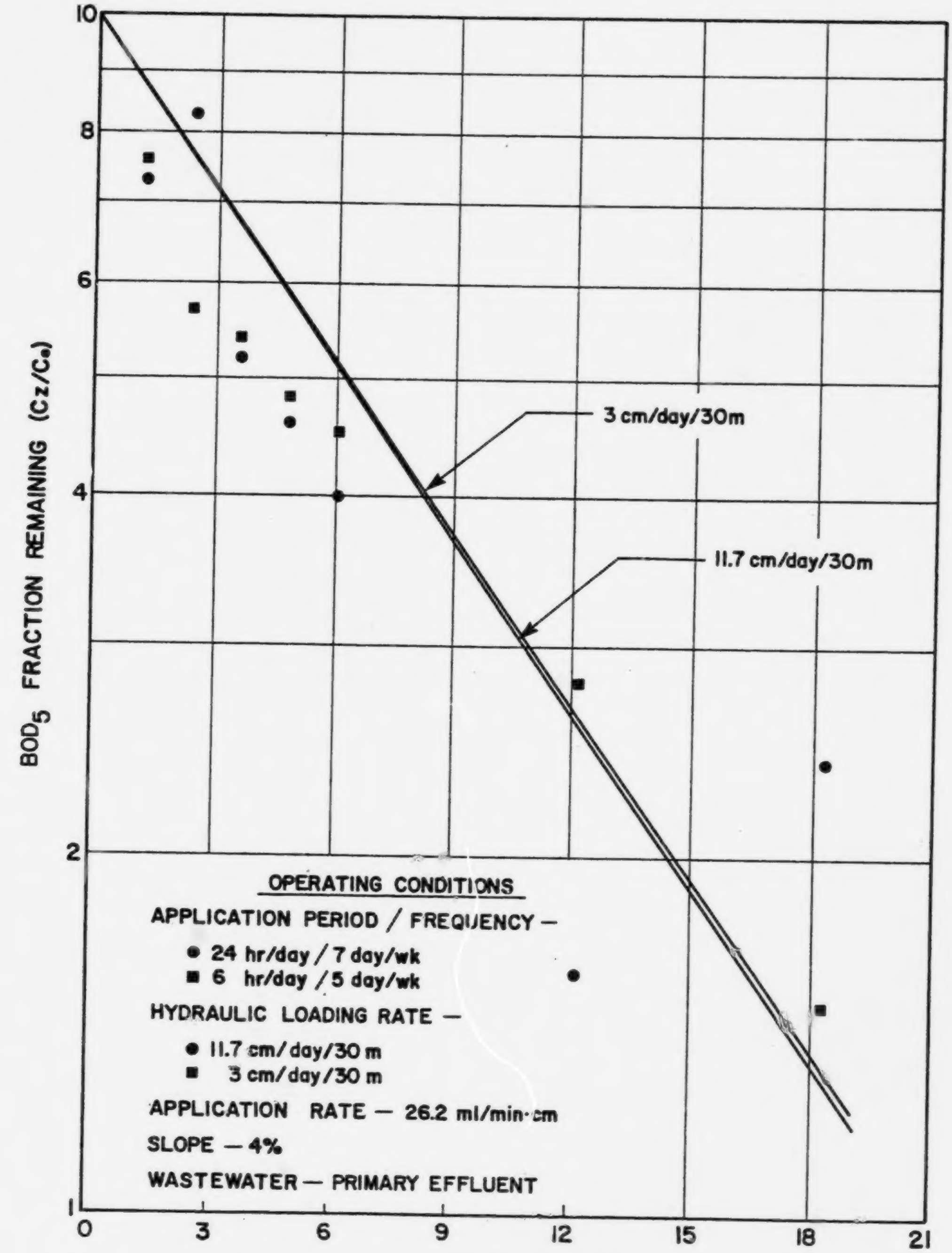

Figure 18. BOD5 Fraction Remaining vs. Down-Slope Distance-Comparison of Hydraulic Loading Rates.

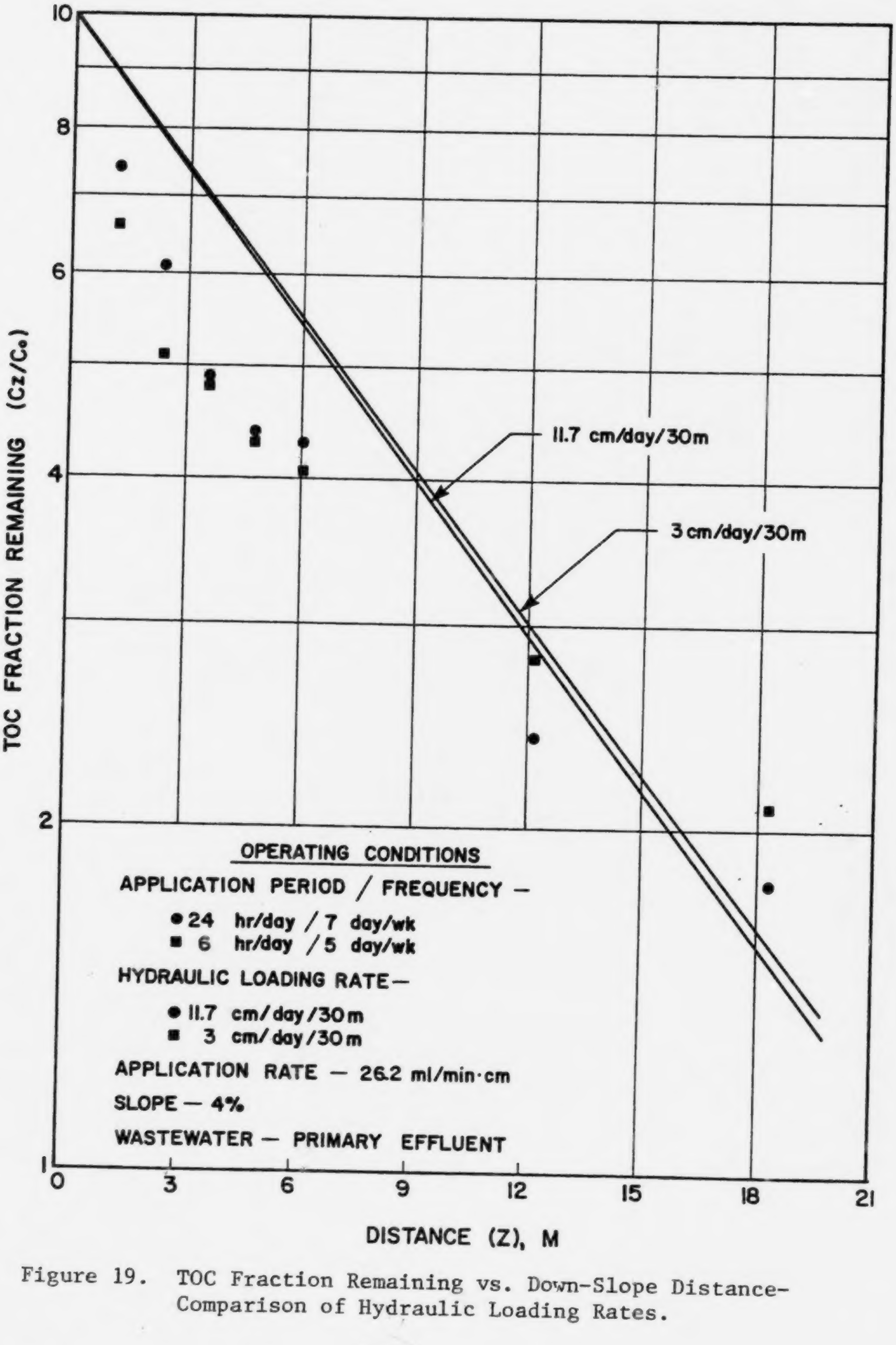

Figure 19. TOC Fraction Remaining vs. Down-Slope Distance-Comparison of Hydraulic Loading Rates.

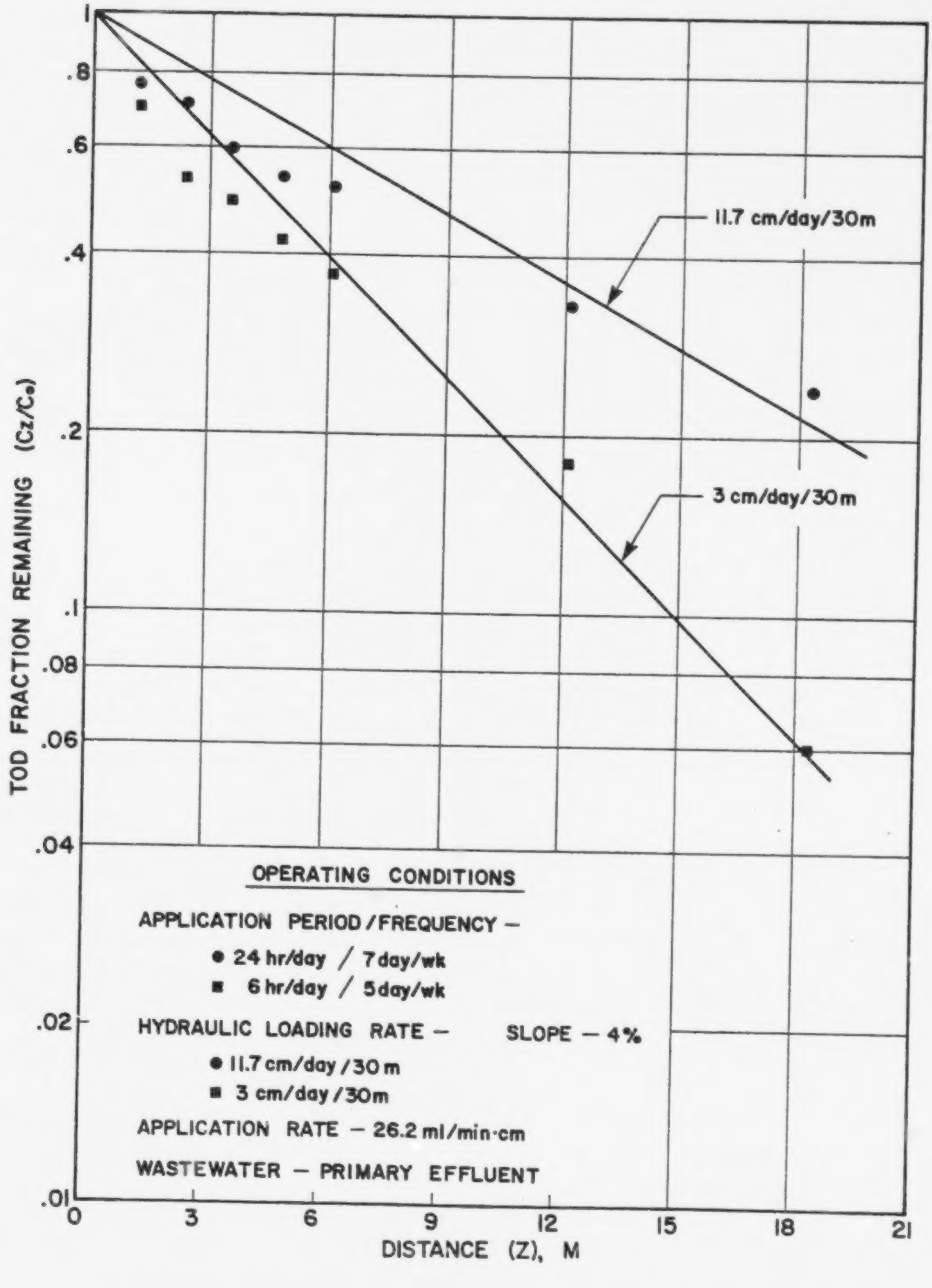

Figure 20. Fraction Remaining vs. Down-Slope Distance-Comparison of Hydraulic Loading Rates.

Table 11

Observed Variation of Organic Removal Rate with Temperature

Study	Regression Coefficient	Temperature Range, °C
Synthetic Wastewater		
Slope Grade	-0.00318	24-28
Application Rate	-0.00287	26-29
Hydraulic Loading Rate	-0.00290	26-29
Primary Effluent		
Application Rate	-0.00142	24-26
Hydraulic Loading Rate	-0.00146	20-24
Extended Length	-0.00154[a]	18-22
Continuous Application	-0.00154[a]	21-24

[a] based on first 6.1 m of travel

Table 12

Filterable And Nonfilterable TOC Of Surface Runoff Samples Taken at Various Down-Slope Distances, mg/L

Run	Sample Fraction	Distance, Down-Slope, m			
		0.0	6.1	12.2	18.3
1	Total	55.0	18.0	11.5	8.8
	Filterable	21.8	13.5	9.8	8.3
	Non-Filterable	33.2	4.5	1.7	0.5
2	Total	54.0	28.4	18.3	11.8
	Filterable	21.6	17.0	14.0	11.8
	Non-Filterable	32.4	11.4	4.3	0.0

To test the degradability of the effluent samples taken after 6.1 m, 12.2 m, and 18.3 m of travel, runoff samples were analyzed for TOC, then aerated for 24 hours and analyzed again for TOC. The results of this experiment are presented in Table 13. It is apparent that no further reduction takes place after 18.3 m of travel.

DISCUSSION

The discussion presented below is focused on the development of a predictive model to describe the removal of organic material in wastewater with the overland flow process and the use of the model as a rational basis for the design and operation of overland flow systems.

Elements of a Predictive Model

Several overland flow design and operating variables were identified as potential parameters to be included in a predictive model describing the removal of organics with the overland flow process. A list of these parameters and the units used for their expression are presented in Table 1. The effect of these parameters on organic removal was studied by observing changes in organic removal efficiency in response to changes in the value of each parameter. The range of values studied for each parameter is indicated in Table 1.

From the studies reported herein, it was found that removal of organic material from primary municipal effluent by overland flow is independent of slope grade, application period, application frequency, hydraulic loading rate and organic loading rate, and is dependent only on the parameters slope length and application rate. Of course, these findings apply only over the range of parameter values studied, as indicated in Table 1. In addition, it was found that removal of organic material from primary effluent can be described by a two-stage model that is only a function of slope length (z) and application rate (q). The model is expressed in the following form.

$$\frac{C_z}{C_o} = \exp\left(-\frac{Kz}{q^n}\right) \qquad \text{(Stage 1)}$$

$$\frac{C_z}{C_o} = A\exp\left(-\frac{K'}{q^{n'}}\right) \qquad \text{(Stage 2)}$$

where C_o = influent organic concentration

C_z = organic concentration at a distance z down-slope

K, K' = empirically determined rate constant, cm/min

Table 13

TOC of Aerated And Non-Aerated Surface Runoff Samples Taken at Various Down-Slope Distances, mg/L

Treatment	Distance, Down-Slope, m			
	0.0	6.1	12.2	18.3
Non-aerated	60.0	21.8	14.5	8.3
Aerated	-	10.8	9.8	8.3

z = distance down-slope, cm

q = application rate, mL/min•cm

n, n' = empirically determined coefficient

A = empirically determined coefficient

The two-stage models for BOD_5 removal and TOC removal are illustrated in graphical form in Figures 13 and 14, respectively. The first stage of the model applies to the first 3 to 6 meters of slope length where the rate of organic removal is most rapid. Stage 2 of the model applies over the remainder of the slope. From a practical design and operation standpoint, the first stage of the model would be of little importance, and the second stage of the model would serve as the basis for design and operation.

The probable reason for the observation of two distinct rates of organic removal over the length of the overland flow slope is that larger suspended matter is removed readily in the first few meters, leaving colloidal and soluble organic material to be removed at a slower rate over the remaining length of the slope. This hypothesis is supported by results from the effluent characteristics study and the CRREL field test, in which it was shown that most of the organics removed in the first 4 to 6 m of travel were filterable. In addition, it was found from the CRREL test that most of the suspended solids were removed in the first few meters of travel.

Values for the empirical coefficients (K and n) in Stage 1 of the model were determined on the basis of 6 m of down-slope travel (see equations 20 and 21). Values for K' and n' in the Stage 2 equation could not be determined because extended length studies were only conducted at a single application rate. An application rate study needs to be conducted on parallel, full-length slopes to determine values for K' and n'. Because n is related to the hydraulic characteristics of the slope, the value of n and n' are expected to be similar. The value of the rate constant for the first stage (K) should be greater than the rate constant for the second stage (K'), because the observed rate of removal is more rapid over the first few meters.

An important feature of the proposed model is that application rate, not hydraulic loading rate, is the principal variable in the model. This feature is important because hydraulic loading rate, historically, has been the principal parameter used in the design of overland flow systems, and it generally has been thought that process performance was related to hydraulic loading rate. Thus, a predictive model based on application rate rather than hydraulic loading rate is a major departure from current thinking regarding overland flow design and operation.

Exclusion of hydraulic loading rate as a model parameter is supported by the recent work of Martel et al (14) at the CRREL facility in Hanover, New Hampshire. This research group also has proposed a model for organic removal by overland flow that does not contain hydraulic loading rate as a model parameter. Details of the CRREL model were described previously in the section on initial model development. However, there are important differences between the CRREL model and the one developed in this report (the UCD model). The CRREL model is based on combined relationships among wastewater detention time on the slope, treatment efficiency, and the parameters, application rate, slope length, and slope grade. In contrast, the UCD model is not based on detention time; rather on a direct relationship between treatment efficiency and the parameters application rate and slope length. Slope grade is not a parameter in the UCD model. Arguments for eliminating detention time from the model are presented in the section on initial model development. Elimination of slope grade as a model parameter is based on arguments presented in the section on initial model development and confirming experimental results from this and other studies (7, 8, 19).

Although the model developed here is empirical, it has a theoretical basis. Considering the complexity of the soil-microbe environment and the current limited knowledge of the interactive processes that occur in that environment, the only possible approach to overland flow model development that can be taken at this time is empirical. The model developed here is straightforward and after field verification, should be useful as a general design tool.

ENGINEERING SIGNIFICANCE

The findings presented here and the models developed on the basis of these findings, have several important implications with respect to the design and operation of overland flow systems used for removal of degradable organic material and suspended solids from municipal wastewaters. A rational overland flow design procedure based on the proposed organic removal model is presented and illustrated with a numerical example. In addition, general design and operating guidelines derived from the pilot studies are set forth.

Rational Design Approach

Under current overland flow design procedures, hydraulic loading rate is the principal design and operating parameter. It was shown through studies reported here that organic removal efficiency is independent of the hydraulic loading rate within a range of values that include those typically used in existing systems. It was further shown that organic removal efficiency depends only on the slope length and the application rate. The model developed to describe organic removal is only a function of these two variables! A new rational design procedure needs to be developed to reflect these findings and to incorporate the model. Such a rational approach to overland flow design is described below.

- General Design Procedure

The general form of the Stage 2 equation of the proposed organic removal model is

$$\frac{C_z}{C_o} = A \exp\left(-\frac{Kz}{q^n}\right) \qquad \text{(Equation 26)}$$

as described previously. The model contains two variables, application rate (q) and slope length (z), either of which may be used as the initially selected or independent design variable. When designing a system, the required or desired level of treatment is known. Thus, a value for (C_z/C_o) can be established. If slope length is used as the independent variable, then a design value for slope length (z) is selected and substituted into equation 26 along with the known value of C_z/C_o. The required value of application rate (q) is then computed using equation 26. Alternatively, if application rate is the independent design variable, then a value for q is selected and substituted into equation 26, and the required value of slope length (z) is computed using the equation. Which parameter to use as the independent design parameter depends on the individual case. Site conditions may dictate the allowable slope length, in which case slope length would be the independent parameter and application rate would be the computed parameter. If slope length is not restricted then application rate should be used as the independent parameter.

To complete the design of a system, the total area required for slopes must be determined. Total area required may be computed using the following equation, assuming an application frequency of 7 days/week.

$$\text{Area} = \frac{(Q)(z)}{(q)(P)} \qquad \text{(Equation 27)}$$

where Q = average daily flow, m^3/day

k = slope length, m

q = application rate, m^3/hr•m

P = daily application period, hr/day

For a given removal efficiency, the required area may be written as a function only of slope length or only of application rate by combining equations 26 and 27. Performing this combination yields the following relationships:

$$\text{Area} = \frac{(Q)\left[-\ell n\left(\frac{C_z}{A\,C_o}\right)\right](q^{n-1})}{(P)(K)} \qquad \text{(Equation 28)}$$

and

$$\text{Area} = \left(\frac{Q}{P}\right)\left[\frac{K}{-\ell n\left(\frac{C_z}{A\,C_o}\right)}\right]^{1/n} z^{(1-1/n)} \qquad \text{(Equation 29)}$$

The value of n in the Stage 1 equation was shown to be less than 1 (approximately 0.5 for BOD removal). It is expected that the value of n in the Stage 2 equation will be similar. Assuming that the value of n is less than 1, the value for area given by either equation 28 or 29 will be minimized when either q or z are maximized. Therefore, the recommended design approach is to select the maximum application rate within the valid region of the model (see Table 1) and compute the required slope length using equation 26. If the computed slope length is greater than that allowed by the site conditions, then the maximum allowable slope length should be selected and the required application rate computed.

The parameter, application period (P), is an independent parameter to be selected by the designer and does not effect treatment efficiency. According to equation 27, the area will be minimized with P is a maximum. The maximum application period, of course, is 24 hrs/day (continuous application). As indicated earlier, the use of continuous application may result in crop damage when the application rate is above a certain, but as yet unknown, value. Thus, selection of P must be based on previous successful experience. Application periods up to 12 hrs/day were used in the primary effluent studies without any apparent adverse affects on the cover crop. Additional field testing will be necessary to define more clearly suitable or safe values of P at given application rates. The effect of the application period on nitrogen removal is not considered in this discussion. If nitrogen or ammonia removal is a design consideration, then the application period may be dictated by nitrogen removal requirements because nitrogen transformations were shown to be sensitive to changes in application period.

- Design Example

The following numerical example is presented to illustrate the design procedure just described.

Assume the following information is known:

1. Average Flow (Q) = 3,000 m^3/day
2. Influent BOD_5 (C_o) = 200 mg/L
3. Required effluent BOD_5 (C_z) = 20 mg/L
4. Stage 2 model coefficients

$A = 0.72$

$n = 0.50$

$K = 0.00415$ cm/min

The necessary design calculations are:

1. Compute the required removal ratio C_z/C_o.

$$\frac{C_z}{C_o} = \frac{20}{200} = 0.10$$

2. Select maximum value of application rate (q) in valid range of the model.

Select q = 40 mL/min•cm

3. Compute required value of slope length (z) using equation 26.

$$\frac{C_z}{C_o} = A \exp\left(- \frac{Kz}{q^n}\right)$$

$$z = \left(- \ell n \frac{C_z/C_o}{A}\right)\left(\frac{q^n}{K}\right)$$

$$= \left(- \ell n \frac{0.1}{0.72}\right) \left(\frac{40.0^{0.5}}{0.00415}\right)$$

$$= 3008 \text{ cm}$$

$$= 30 \text{ m}$$

4. Select application period (P).

$$P = 12 \text{ hrs/day}$$

5. Convert q to units of m^3/hr•m.

$$q = \frac{(40 \text{ ml/min•cm}) (60 \text{ min/hr}) (100 \text{ cm/m})}{10^6 \text{ mL/m}^3}$$

$$q = 0.24 \text{ m}^3\text{/hr•m}$$

6. Compute required total area. Assume 7 day/week application frequency.

$$\text{Area} = \frac{(Q)(z)}{(q)(P)}$$

$$\text{Area} = \frac{(3{,}000 \text{ m}^3\text{/day}) (30 \text{ m})}{(0.24 \text{ m}^3\text{/hr•m}) (12 \text{ h})}$$

$$\text{Area} = 31{,}250 \text{ m}^2 = 3.1 \text{ ha}$$

The required area of 3.1 ha is considerably less than would be calculated using existing design criteria. Using 3 cm/day as a typical hydraulic loading rate currently used for design, an area of 10 ha would be calculated. The implication is that current design criteria may be quite conservative. However, judgement on the question of conservatism of current design criteria must be withheld until the proposed organic removal model can be tested and verified in the field.

The design procedure outlined above, meets the objective of providing a rational approach to the design of overland flow systems. Once verified by field testing, this procedure will provide a basis for optimizing overland flow design.

Design and Operating Guidelines

The following general guidelines for overland flow design and operation are based on the findings from the Phase I pilot studies. The guidelines are based on treatment of municipal primary effluent, but are also expected to be valid for raw municipal wastewater.

1. Removal of organic material is independent of slope grade in the range of 2 to 6 percent. Thus, slope grade is not a critical design parameter in this range.

2. Removal of organics from primary effluent by overland flow is independent of hydraulic loading rate and application period and dependent only on application rate and slope length. Therefore, the following effects can be expected.

    a. The hydraulic loading rate can be increased on a given slope without affecting the organic removal efficiency. This can be accomplished by increasing the period of application while maintaining a constant application rate.

    b. Decreasing the application rate will improve the organic removal efficiency over a given length of slope.

    c. Improved organic removal efficiency can be achieved on a given slope without reducing the hydraulic loading rate by decreasing the application rate and increasing the application period.

3. Overland flow systems may be operated continuously at application rates in the range of 20 to 30 m/min·cm for short periods of time (3 weeks or less), without affecting organic removal efficiency. If surface application is used, solids build-up may occur at the top of the slope that could damage the cover crop if continued over longer periods.

4. Continuous application will significantly reduce nitrification on the slope.

5. Removal of organics from primary effluent is independent of temperature in the range of 18 to 28°C.

6. Design of overland flow systems should be based on the parameters - application rate, slope length, and application period, rather than the hydraulic loading rate.

CONCLUSIONS

The conclusions derived from this study are:

1. Removal efficiency of degradable organic material from municipal primary effluent by the overland flow process is:
   a. Independent of slope grade in the range of 2 to 6 percent.
   b. Independent of hydraulic loading rate in the range of 2 to 11.7 cm/day based on a 30 m slope length.
   c. Independent of application period in the range of 4 to 24 hrs/day.
   d. Independent of wastewater temperature in the range of 18 to 28°C.
   e. Dependent only on the application rate and the slope length.
2. Removal of organic material from municipal primary effluent by overland flow can be described by a two-stage predictive model of the following general form:

Stage 1

$$\frac{C_z}{C_o} = \exp\left(-\frac{Kz}{q^n}\right)$$

Stage 2

$$\frac{C_z}{C_o} = A\exp\left(-\frac{K'z}{q^{n'}}\right)$$

where C_z = organic concentration at a distance (z) down-slope

C_o = initial organic concentration

K, K' = empirically determined rate constant, cm/min

z = distance down-slope, cm

q = application rate, mL/min•cm

n, n' = empirically determined coefficient

A = empirically determined coefficient

The first stage of the model applies over to first 4 to 6 m of the slope and the second stage applies over the remaining slope length.

3. The proposed predictive model for organic removal can be used as a basis for the rational design of overland flow systems.

4. Using the rational design approach developed from this study, the total area required for an overland flow system that will achieve a specified level of treatment can be minimized by designing the system on the basis of a maximum application rate.

5. Removal of suspended organic material on an overland flow slope occurs primarily within the first 4 to 6 m of down-slope travel.

6. The removal rate of purely soluble organic material from wastewater by overland flow appears to be affected by organic loading rate above a limiting value between 45 and 90 kg BOD_5/ha•day based on a 30 m slope length.

7. Continuous application of primary effluent for a period of 3 weeks or less does not affect the organic removal efficiency. If continuous application is sustained for longer periods at application rates of 26m/min•cm or more, the cover crop may be damaged due to smothering by deposited solids and slime buildup.

8. Continuous application significantly reduces nitrification.

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Question (by Mr. Ted Stackley, Nebraska Department of Environmental Control, Lincoln, NE): What was the significance on the long-term effect of harvesting grass as pertaining to the overall efficiency of the system?

Response (By Dr. Smith): We did not do a control plot of nonharvesting in our work. However, I am familiar with a study in Carbondale, Illinois that did a side-by-side study of harvesting versus nonharvesting. That study showed, in terms of BOD and Nitrogen removal, that there was no practical difference between the two in terms of peak performance. The study was dealing with very long slopes, 200 to 300 feet, and the results may be influenced by the long slopes, but that is one study that has been done side-by-side.

PB82-194341

The Easley, South Carolina, Overland Flow Project

A. Ray Abernathy, Professor
Environmental Systems Engineering Department
Clemson University, SC

The Easley project began in November, 1976 with funding by the U.S. Environmental Protection Agency through a research grant (later a cooperative agreement) to the South Carolina Department of Health and Environmental Control. That agency in turn contracted with the Easley Combined Utility System to be the builder/owner/operator and with the Environmental Systems Engineering Department of Clemson University for supervision and monitoring.

The objectives of the Easley Project are summarized in Table 1.

Table 1. Project Objectives

1. Design and construct overland flow systems to treat:
    - 75,000 gpd oxidation pond effluent
    - 25,000 gpd comminuted raw sewage.
2. Evaluate system performance with respect to removal of carbon, nitrogen, and phosphorus from applied wastewater.
3. Improve knowledge of criteria for designing and operating such systems.
4. Estimate mechanisms controlling removals.
5. Evaluate potential for groundwater pollution or nuisance problems.

It was desired to test overland flow in western South Carolina, a region of high rainfall, mild winters, and relatively impermeable soils. Both comminuted raw sewage and lagoon effluent would be treated on overland flow plots. A series of criteria for selecting a site was developed including:

(1) The site should be within 25 miles of Clemson University.
(2) The population of the town must be at least 1000.
(3) The site must have an existing facultative lagoon.
(4) The use of overland flow must be compatible with any regional wastewater management plans.

The site we finally chose was at Easley, SC. There was an existing nine-acre lagoon just across a county road from an open field having slopes of three to six percent. The Combined Utility System was able to purchase twenty acres of that land for the overland flow project. The sewer line to the lagoon crossed the property purchased. Figure 1 shows the layout of the project including the lagoon location, sewer line, separate overland flow plots, collection channels, chlorination facility, and receiving stream.

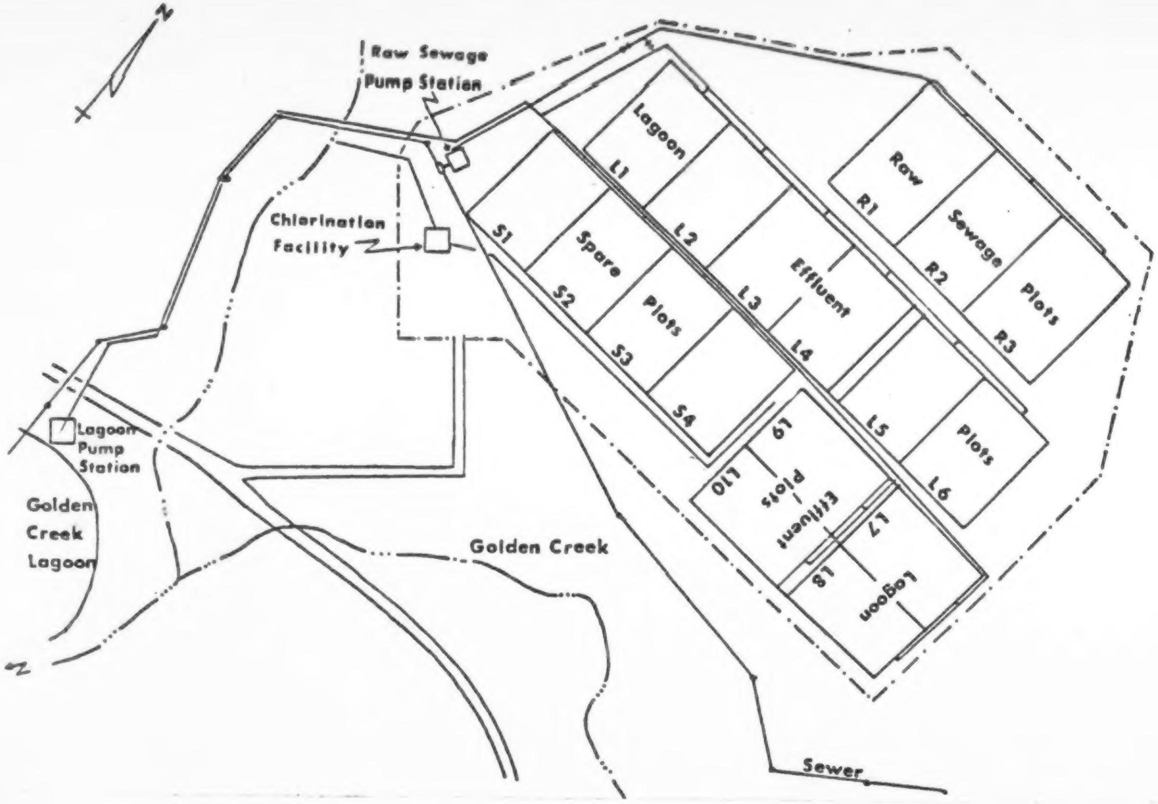

Figure 1. Overland Flow System, Easley, S.C.

DESIGN

A slope of 4% was selected for all plots. Three plots 110 feet wide by 165 feet long were designed for raw sewage application. The remaining plots were built 100 feet wide and 150 feet long for receiving lagoon effluent.

We planned to apply lagoon effluent at rates of 4 inches per week, up to 8 inches per week. A single application rate of 4 inches per week was chosen for the raw sewage system. Raw sewage application was planned for six hours per day, 5 days per week, whereas lagoon effluent would be applied according to the schedule shown in Table 2.

Kentucky 31 Tall Fescue was selected for the cover crop. It was seeded along with rye at three times the rate used for establishing permanent pasture in our area. We fertilized according to Cooperative Extension Service recommendations based on the results of soil tests. We had real problems in establishing the grass — a dry fall, unusually cold winter, erosion during late winter and spring. It took much extra work to relevel the plots and to reseed.

Low pressure spray nozzles on risers attached to solid set piping was the distribution system chosen for all plots. Later, we used a gated pipe distribution system for raw sewage application.

Construction was attended by the usual problems — wet weather, cold weather, equipment breakdowns, and delays in shipment. Finally, everything was ready in January 1979 for startup. Table 3 contains a summary of construction costs; note that many extra costs were incurred because of research requirements.

Table 3. Construction Costs

1.	Land purchase, 20 acres	$ 40,000
2.	Site preparation	34,940
3.	Mechanical, electrical and concrete	83,832
4.	Equipment	13,766
5.	Engineering fees	12,000
	Total Construction Costs	$184,538

Startup revealed the usual number of problems: improperly assembled pumps; clogging of spray nozzles; coagulation of comminuted sewage into a dense sludge which settled to the bottom of the wet well. The nozzles on the raw sewage distribution system clogged and were replaced with gated pipe. The raw sewage pumping system worked well when operated on an on-off cycle of approximately ten minutes. This did not allow enough time for the comminuted solids to agglomerate. After equipment problems were ironed out and the grass was well established, the system operated well.

Table 4 shows the costs of operation for a continuous, 12-month period. The operator charged to this project helped to make piping changes, modify

Table 2. Application Rates and Frequencies

Wastewater	Design Flow (Based on 7-day week)		Operation	Applied Flow (Based on 5-day week)	
	gpd	gpw	(Days/Week)	gpd	gpw
Raw Sewage	24,000	168,000	5	33,600	168,000
Lagoon Effluent	76,000	532,000	5	106,400	532,000
TOTAL	100,000	700,000		140,000	700,000

Plot	Waste-water	Application Time (hrs)	Application Rate (gpm)	Volume Applied Per Day (gallons)	Areal Loading Rate	
					(in/day)	(in/wk)
R1	Raw	6	31.11	11,200	0.93	4.67
R2	Raw	6	31.11	11,200	0.93	4.67
R3	Raw	6	31.11	11,200	0.93	4.67
L1	Lagoon Effluent	7	19.33	8,119	0.87	4.06
L2	Lagoon Effluent	7	25.33	10,639	0.14	5.69
L3	Lagoon Effluent	8	29.99	14,395	1.52	7.60
L4	Lagoon Effluent	7	25.33	10,639	1.14	5.69
L5	Lagoon Effluent	6	29.90	10,764	1.15	5.76
L6	Lagoon Effluent	7	31.33	13,159	1.41	7.04
L7	Lagoon Effluent	5.5	25.33	8,359	0.89	4.47
L8	Lagoon Effluent	8.5	25.33	12,918	1.38	6.91
L9	Lagoon Effluent	6	21.10	7,596	0.81	4.06
L10	Lagoon Effluent	8	21.10	10,128	1.08	5.42
S1	Spare	Plot				

Table 4. Operating Costs

12 months - August 1, 1979 to July 31, 1980	
Electrical power	$ 753.60
Labor	
1/2 time for one operator	8,940.00
Mowing and grass removal	500.00
Chemicals and supplies	450.00
	$10,643.60

distribution systems, and collect samples. Otherwise, one-quarter operator time would probably have been sufficient. The grass was mowed, raked, and baled two times during the period of operation covered.

RESULTS

Table 5 is a list of the parameters monitored for this project and Table 6 contains a summary of twelve months of operating results.

Table 5. Parameters Monitored

Biochemical oxygen demand	Total organic carbon
Soluble BOD	Dissolved organic carbon
Total suspended solids	Total phosphorus
Volatile suspended solids	Orthophosphate phosphorus
Fecal coliforms	Total Kjeldahl nitrogen
Fecal streptococci	Ammonia nitrogen
	Nitrate nitrogen

Both systems performed reliably. The solids in raw wastewater were removed more completely than algal cells produced in the lagoon. On the other hand, the BOD_5 of the wastewater pretreated in the lagoon and then on the plots was lower. Nutrients were also more effectively removed by the combined treatment.

Figure 2 shows a typical profile of BOD_5 removal from raw sewage as it flowed down one plot. Suspended organic solids are rapidly removed. Figure 3 shows a summary of BOD concentrations for the entire system. Table 7 contains typical bacteriological results from a raw sewage plot.

We have installed water meters on four lagoon plots along with stage recorders at the V-notch weirs at the foot of the slopes. Hydraulic studies during this past summer indicate that from 72% to 78% of the wastewater (both raw & lagoon effluent) applied was recovered as runoff. If we adjust the concentration removals shown earlier, then the removal efficiency on a mass basis is even greater.

I should add here that Easley has shut down the entire system for mowing,

Table 6. Mean Performance of Overland Flow System

Parameter	Raw Sewage	Lagoon		Overland Flow System			
				Lagoon Effluent		Raw Sewage	
	Conc. (mg/l)	Conc. (mg/l)	Removal (%)	Conc. (mg/l)	Removal (%)	Conc. (mg/l)	Removal (%)
Biochemical Oxygen Demand	200	28	86	15	47	23	86
Dissolved Organic Carbon	31.1	23.1	26	24	0	23	25
Total Suspended Solids	186	60	68	40	33	8	96
Volatile Suspended Solids	149	58	61	37	35	6	96
Total Phosphorus (as PO_4)	8.9	3.8	57	2.2	43	4.0	56
Ortho Phosphate (as PO_4)	6.6	3.0	54	1.7	42	3.8	42
Total Kjeldahl Nitrogen (as N)	29.1	4.3	85	1.0	16	7.4	70
Ammonia Nitrogen (as NH_4)	19.4	1.0	95	0.4	58	4.0	79
Nitrate Nitrogen (as NO_3)	6.0	2.4	60	1.1	52	1.2	79

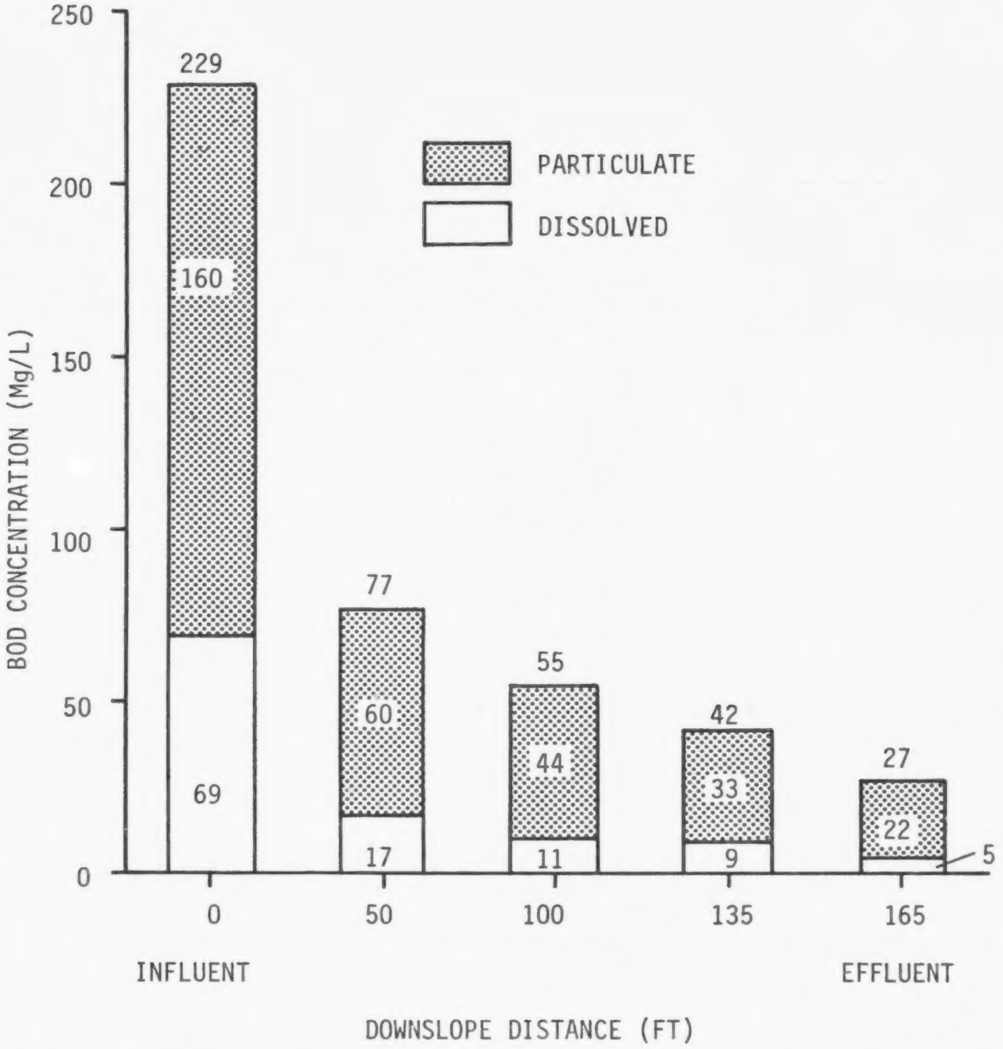

Figure 2. Biochemical Oxygen Demand Profile

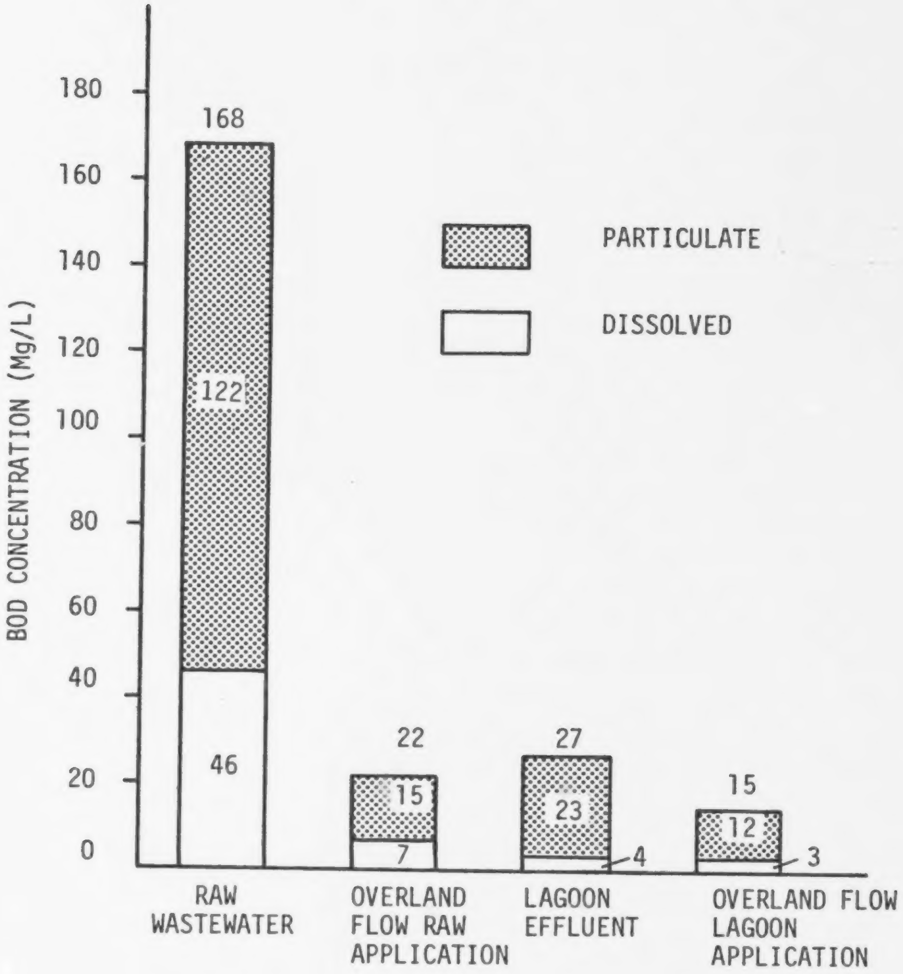

Figure 3. Mean BOD Concentrations

Table 7. Typical Bacterial Results

Distance Down Slope (feet)	Fecal Coliforms (no/100 ml)	Fecal Strep. (no/100 ml)
0	3,800,000	5,180,000
25	5,800,000	4,800,000
50	2,500,000	6,400,000
75	1,800,000	3,180,000
100	320,000	3,120,000
135	1,100,000	2,800,000
165	400,000	1,010,000

using the lagoon for storage during the period. Start-up after mowing results in reduced treatment efficiency for at least a week. Increases in the effluent concentrations of BOD, NH_3, TKN, and organic carbon to about twice their normal values have been observed. The extremely hot, dry weather this summer accentuated this effect. This points out the advantage of mowing the plots in stages.

Conclusions

1. Overland flow can successfully treat comminuted raw sewage producing an effluent comparable to conventional secondary effluent or even better.

2. Overland flow can successfully polish lagoon effluent removing from 33% to 45% of the suspended solids and BOD_5 remaining after lagoon treatment.

3. Application rates of from 4 inches per week to 8 inches per week of raw sewage or lagoon effluent can be effectively treated.

4. Operating costs seem reasonable. This project resulted in less than 30 cents per thousand gallons operating costs.

5. Effluent quality decreases after shutdown for grass harvesting.

6. Preliminary studies do not indicate that ground water is affected at this site nor that viable bacterial aerosols are a real problem.

7. The community plans to operate this overland flow system as a continuing part of their sewage treatment facilities.

Question (by Mr. Dan Sherwood): I have two questions, both involved with esthetics.

Number one, there were several panelists who discussed the practicality of a rock apron or something to distribute the pipe-type distribution system on it. I was wondering if you might encounter any problem with odors from growths on the rocks.

Question number two: It looks as if a rock apron would create a perpetual wetland problem with mosquito breeding. How would you try to eliminate this?

Response (by Dr. Abernathy): We had no problem with mosquitos. We have utilized the gravel pad to prevent erosion or disruption of the soil structure and the pattern of direct application. I think it is a good idea to have such a gravel pad to prevent erosion and disturbance of the pattern of application and to start good distribution as the water begins moving down the slope.

We have not noted a mosquito problem. We have really seen that crickets and grasshoppers have grown like crazy in these plots, and I was told that some of the local bait fishermen have asked to come in and collect bait.

Question (by Mr. Don Deemer, Technological Resources, Inc., Camden, NJ): I would like to ask each of the afternoon speakers to address briefly high-pressure sprinkler application versus other methods.

Response (by Dr. Abernathy): We chose the low-pressure, fan-type nozzles because of operating costs, pump sizes required, and needed pressures of 15 to 20 PSI in order to operate. They have performed satisfactorily where we were applying the wastewater treated in the lagoon. We did not have successful operation applying wastewater with a lot of solids. I do not have personal experience with projects using the high-pressure, impact-type spray nozzles.

We have noted a considerable buildup of organic solids in the immediate vicinity of the gravity distribution system that I showed you in the slide, but so far, we see no problems associated with that buildup of solids. In fact, we may be getting improved treatment because of the organic mat in the vicinity of the application system.

We seem to note a much higher efficiency of removal of the solids, suspended BOD, in that first 25-foot flow distance; and also we begin to see nitrification and denitrification--partially, we think, because of the organic mat that has built up.

Additional Comments (by Dr. Lawrence): At the Pauls Valley project, we did not use the high-impact distribution method. Of the three methods that we did use, the trough, which was actually a horizontal pipe with frequent orifices on three-foot centers, was by far the best method from the standpoint of distribution across the top of the plot. Also, from the standpoint of low-clogging problems and of moving equipment around on the plots for mowing, etc., it was by far the best method.

Additional Comments (by Mr. Peters): At Utica, MS, we used a surface application system--a rain gutter-type arrangement commonly found around the eaves of houses. We used a stiff backing of aluminum to hold it rigid and then had holes cut out at the bottom to allow the water to trickle out across the plot to produce an even distribution.

However, if we were recommending something for a municipality to use, we are a little bit partial to the surface application systems. They have some advantages that I think are important. One is that you usually don't have people talking to you about aerosol problems. The second is that you do have lower energy requirements. A third one, that you reduce your mechanical clogging.

Additional Comments (by Mr. Bledsoe): Our experience was with the rotating booms and fixed risers. We applied raw wastewater over the same plot with the same circular spray pattern for as long as seven years. No buildup of the solids occurred. When we changed to fixed risers and applied to the gravel pack, we did see a buildup of the solids on the gravel. After they reached a certain point, the buildup seemed to be degrading as fast as solids were being applied to it, and we did not remove the buildup.

Question (by Mr. Richard Corneille): I want to ask the panelists how they feel about the final disposal of the grass that is harvested from the slopes. Dr. Abernathy mentioned that it is salable. Is it possible to use it as fodder? Has anybody had an experience with just chopping the grass and leaving it on the slopes?

Response (by Dr. Abernathy): We have not officially sought approval to feed the hay to livestock. For the plots that receive lagoon effluent, I would not have any personal reluctance to feed the hay to livestock, but I have not tried to get permission to use it. The combined utility system uses this hay to prevent erosion on pipeline right-of-ways, road cuts, etc. Nobody, at least not officially, is using it for cattle feeding purposes.

I think that there would be at least a theoretical reduction in treatment efficiency if you chop the grass and leave it there. As it decays, it would increase the loading rate, and some of the grass would be down near the toe of the slope, and thus not have much distance for the organic material to be removed. Whether or not in practice this would increase the concentration of the BOD or solids in the effluent, I cannot say.

Additional Comments (by Mr. Thomas): The microbiological study in Paris, Texas was done by North Texas State University. I don't know if that publication is still available. The results were published in journals, so it could be sought out, and the professor there was a Dr. Vela.

Additional Comments (by Mr. Deemer): That information is published in "Publications in Climatology," Vol. XXII, Number 2, September 1969. You may obtain copies by contacting me directly.

PB82-194358

The EPA Land Treatment Task Force

Richard Duty, Chief
Land Treatment Task Force
Robert S. Kerr Environmental Research Laboratory
U.S. Environmental Protection Agency, Ada, OK

The Land Treatment Task Force has been in operation two years. Our basic mission is to encourage and promote, wherever practicable, viable land treatment systems. Part of our job has been to assist in gaining public acceptance of land treatment, and we have learned over the last few years that we are dealing with a very intelligent public who have some real concerns about land treatment, and who require some straightforward assurances before they are going to accept and vote the bond issue or the sales tax, to build these sytems. I am pleased to be moderator of this session, because the subjects we have before us are some of the concerns that the public has about land treatment in general, and overland flow in specific.

The public is concerned about organics, health aspects, and groundwater pollution as it applies to nitrates. We, as professionals, need to be prepared to mitigate these concerns and use the highest technology available to us as we design, operate, and maintain these systems.

I also want to tell you that the Task Force, over the last few years, has produced and accumulated a number of what we believe to be good public education tools. The reason why we accumulated them is so that they would be available to people like you.

I will describe some of them briefly. Most of you will have picked up the health effects brochure that we developed within the last six months. If anyone has need for a supply of them, you will find that each regional I&A coordinator will have a supply. If these stacks run out or you need more, you can contact the Task Force at the Ada Research Laboratory. We will be glad to supply you with more copies.

Also, I laid out on the table out there the first brochure that we ever developed, which was a land treatment brochure intended for the public that explains the three types of land treatment systems, the Construction Grants Program, and gives a general overview of land treatment. Those brochures would only be available through the Task Force at Ada. I don't believe the regional I&A coordinators would have a supply.

The third public education tool that we have developed and are very proud of, is a 15-minute slide-tape show. The one we have available for you now is a second, improved version. The original version of the slide-tape show contained some seven case histories of slow-rate systems in the nine-State area comprising Regions VI and VII. Since this slide-tape show was used also outside Regions VI and VII, we revised and updated it about six months ago. In that updating we removed three of the slow rate systems and added the overland flow system case history at Easley. We added a high-rate system at Phoenix, AZ., as well as a feature on energy saving.

We used a study by Metcalf and Eddy, primarily where it discussed land treatment versus advanced waste treatment for Lake Tahoe and showed that the land treatment option produced 28 percent savings on construction costs, 50 percent savings of primary energy, and 80 percent savings in secondary energy.

This slide-tape show is available and has been modified for national use. Each regional I&A coordinator in the nation has a copy. If you should find that their copy is on loan at the time you need it, we have a large supply of them in Ada, and we will be happy to make them available to you for as long as you need them.

We also have two public education films--16-millimeter sound-color films, running about 30 minutes. One of them was developed in 1976 by Shaffer and Rowland and Consulting Engineers in Chicago, entitled, "Wastewater Bonanza." The other is a brand new film called, "Water Passages," which was developed by Public Broadcasting Service in Oregon. Both these color films are highly land treatment oriented, promotional-type films. Both these color films are highly ideal for showing to the general public.

These are five education tools which we have, or your regional I&A coordinators have. We developed them for your use and hope that you will utilize them at public meetings, workshops, or wherever you have a need or opportunity.

PB82-194366

Removal of Organics by Overland Flow

C. James Martel
John R. Bouzoun
Thomas F. Jenkins
U.S. Army Cold Regions Research and Engineering Laboratory

INTRODUCTION

Many studies have shown that overland flow systems can effectively remove organics from municipal and industrial wastewaters. Thomas et al. (1) concluded that a well-operated system can effectively treat raw wastewater and reduce biochemical oxygen demand (BOD) in the runoff to 10 mg/L or less. McPherson (2) reports a BOD removal efficiency of 95 percent at the Werribee Farm site. C.W. Thornthwaite Associates (3) found BOD removals of 99 percent at the Paris, Texas, site which treats high-strength cannery wastes.

The mechanisms responsible for organic removal are sedimentation, filtration and biochemical oxidation (4). Sedimentation and filtration remove the particulate fraction which eventually decomposes and becomes incorporated into the soil. The soluble fraction is oxidized by microorganisms which are probably similar to the attached growth found in trickling filters. Because of the washout of these microorganisms and redissolved constitutents in the plant-soil system, runoff BOD concentrations below 3 to 5 mg/L should not be expected (5).

To better understand the behavior of these mechanisms and the kinetics of organic removal, a study was conducted at the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, NH. This study was part of a more comprehensive research project which was also concerned with removal of suspended solids, nutrients, and trace organics. The primary objective of this project was to develop a rational procedure for design of overland flow systems. Development of this procedure has been completed and is reported in a previous paper (6). The present paper will focus on the BOD, total organic carbon (TOC) and trace organic removal findings of this project.

DESCRIPTION OF CRREL SITE

The CRREL overland flow test site has been in operation since June 1977. This site is 30.5 m long, 8.8 m wide and graded to a 5% slope. It is divided into three equal sections, designated A, B, and C, so that parallel studies can be conducted. Underlying the soil at a depth of 15 cm is a rubber membrane which prevents downward percolation. The grass cover on this site is a mixture of many species including tall fescue, orchardgrass, Kentucky bluegrass and quackgrass (6). A schematic of the CRREL overland flow test site is shown in Figure 1.

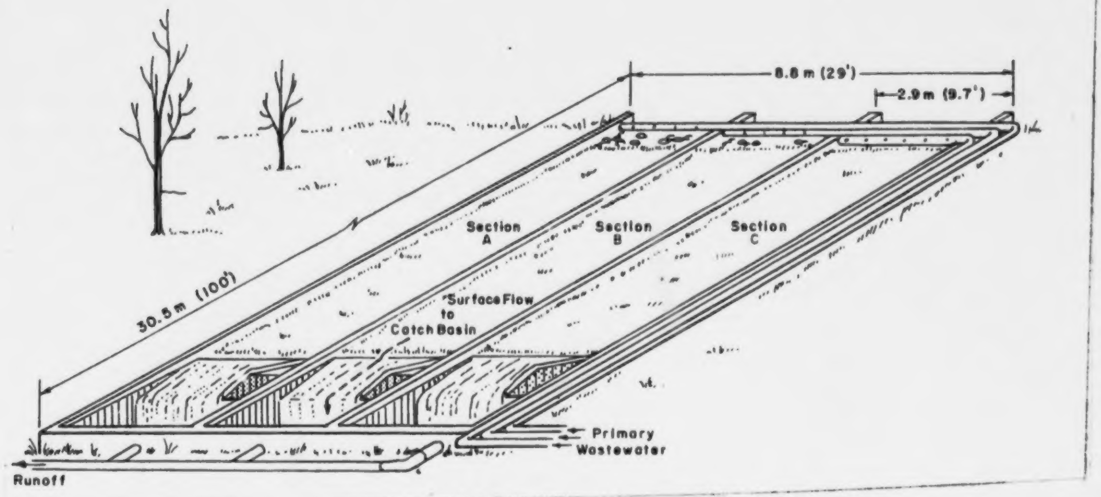

Figure 1. CRREL overland flow test site, Hanover, NH.

Undisinfected primary effluent was distributed at the top of each section by a perforated plastic pipe. The application cycle was 7 hours/day, 5 days/week. The average BOD concentration in this effluent was 72 mg/L. Although this is a lower BOD than found in most primary effluents, it should be typical of the type of wastewater applied to overland flow because most systems will need a storage pond to contain wastewater flows during inclement weather and maintenance operations. Effluent from this pond will dilute the wastewater prior to application.

Runoff was collected at the base of each section in galvanized steel catch basins. Water meters were used to record the volume as it was discharged. The amount of runoff varied depending on antecedent moisture conditions, precipitation and evapotranspiration. During hydraulic steady-state conditions (i.e. when the runoff rate remained constant) the runoff flow rate ranged between 60 to 90 percent of the applied flow rate.

MECHANISMS

To examine the behavior of the mechanism responsible for organic removal, samples were taken of the applied wastewater and runoff and the surface water at various points on the slope. These samples were analyzed for TOC, BOD, and suspended solids. The application rate during this study was 0.124 m^3/hr per meter of width, and the detention time was 67 minutes.

Data obtained from this study clearly indicated that most of the organic solids were removed at the top of the slope. As shown in Figure 2, the total suspended solids concentration was reduced from 77 to 13 mg/L within the first 3.8 m. Similar large reductions in BOD and unfiltered TOC occurred within the same distance. These reductions were caused by the rapid settling of the particulate fraction. Effective settling of particles is probably due to the shallow depth of water on the slope and the grass and

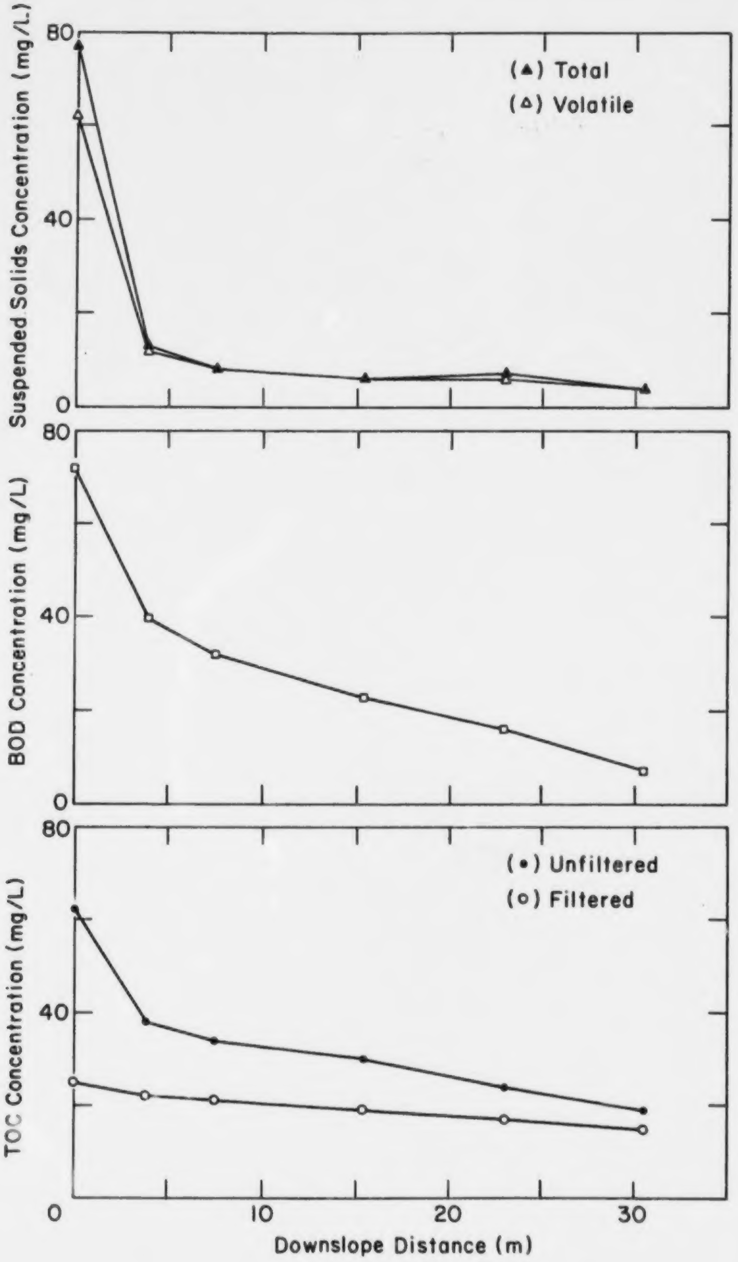

Figure 2. Concentration of suspended solids, BOD and TOC vs. downslope distance on Section C (25 June 1980).

vegetative litter that act as filters to screen out particulates. The gradual reduction in BOD and TOC after the first few meters probably resulted from biochemical oxidation.

Because of the rapid settling of particles, a buildup of solids can be seen at the top of most overland flow sites, with the heaviest concentration usually occurring in low spots. In some cases, solids deposition can be heavy enough to smother grass growth. At the CRREL site, most of the solids appear to be confined to the area between the distribution pipe and 3 m downslope. No odors were associated with this buildup. After three years of application, solids accumulation does not yet appear to be a problem. It is expected that deposited solids will eventually decompose and become incorporated into the soil.

EFFICIENCY OF REMOVAL

There are many variables which can affect the performance of an overland flow system, including application rate, slope length, width and gradient, and surface roughness. Instead of analyzing the importance of each of these variables separately, it was decided that a better approach would be to relate treatment efficiency to the more fundamental variable of detention time. In the case of overland flow, detention time is defined as the average time it takes for water to flow from the top to the bottom of the slope. Theoretically, any desired level of treatment can be achieved by controlling the length of time wastewater remains in contact with the soil surface. This approach has an added advantage in that site preparation would be reduced because existing terrain contours could be used as long as detention time requirements are met.

Detention time was measured by tracer studies using sodium chloride. Chloride was selected as the tracer because it is conservative and easily analyzed. The tracer was applied after hydraulic steady-state conditions had been reached. The time to the peak of the tracer response curve was assumed to represent detention time. Fifty detention time measurements were taken over two application seasons (April through October). Detention times ranged between 20 and 120 minutes.

The relationship obtained between BOD removal (E) and detention time ($\bar{T}$) is shown in Figure 3. Included in this figure are three data points obtained from detention time studies conducted by Smith and Schroeder (8) at the University of California at Davis. The line of best fit for these data indicates that BOD removal can be expressed as a first-order equation in the form

$$E = (1 - Ae^{-k\bar{T}})100 \qquad \text{[Equation 1]}$$

The coefficients A and k obtained from a least-squares fit were 0.52 and 0.03 min^{-1} respectively. By rearranging terms, the detention time required for a desired degree of BOD removal can be calculated. For example, 90% BOD removal would require a detention time of 57 minutes.

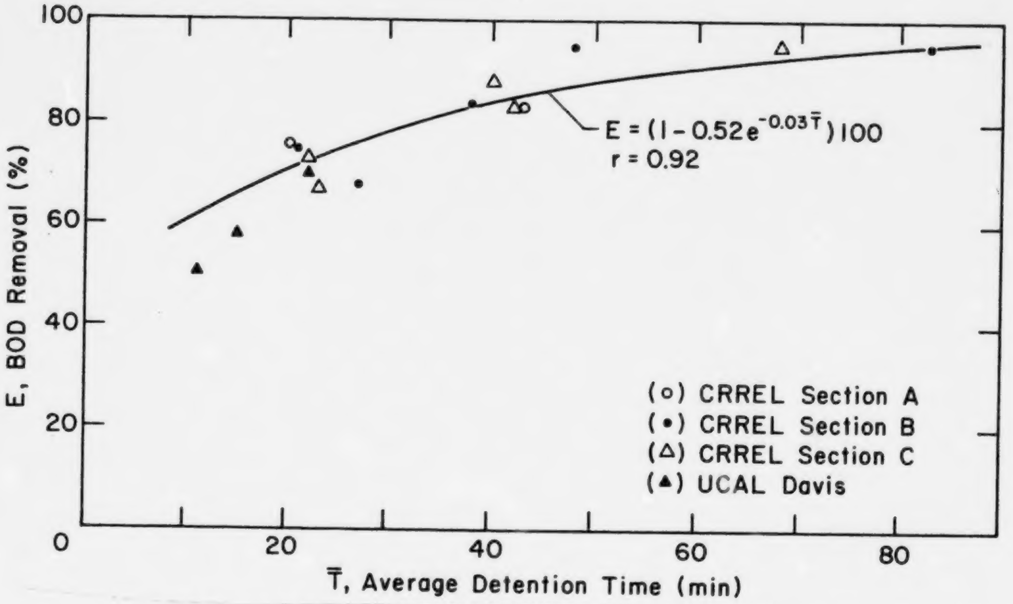

Figure 3. BOD removal efficiency vs. detention time.

The coefficient A can be interpreted as the non-settleable (volatile) fraction of the BOD in the applied wastewater. As discussed earlier, the settleable fraction was removed during the first few meters at the top of the slope. The detention time at this point can be assumed to be negligible. Thus the fact that equation 1 predicts 48% BOD removal at zero detention time is not unreasonable.

The coefficient k is an empirical reaction rate constant determined under the varying size waste loads and temperatures experienced during two years of operation. The value of k obtained in these experiments (0.03 min^{-1}) was greater than the 0.022 min^{-1} value obtained by Asaturians (9). One possible explanation for this difference is that Asaturians used oxidation pond effluent in his experiment. Usually the organics remaining in a pond effluent are less biodegradable than those in primary effluent.

Once the detention time is determined, a method is needed to predict the application rate for a potential site. An empirical relationship developed from Poiseuille's formula and calibrated with CRREL data is

$$q = \frac{0.078\ L}{S^{1/3}\ \bar{T}} \qquad \text{[Equation 2]}$$

where

q = average overland flow rate, m^3/hr per meter of width

L = length of terrace, m

S = slope of terrace, m/m

$\overline{T}$ = detention of time, min.

This relationship was validated using detention time data from overland flow sites in Utica, Mississippi, and at the University of California at Davis. The average difference between actual and predicted detention times was found to be not significant at the 95% level. An example of how to use this relationship in design can be found in a previous paper (6).

TEMPERATURE EFFECTS

To determine the effect of temperature on BOD removal, the CRREL overland flow site was operated throughout the winter of 1977-1978. A plot of the average weekly BOD concentration in the runoff vs. soil temperature is shown in Figure 4. A reasonable correlation (r = 0.78) was obtained with a second-order polynomial fit to the data. At an application rate of 0.083 m^3/hr per meter of width (5.0 cm/wk), BOD concentrations exceeded the secondary effluent standard of 30 mg/L at soil temperatures at or below 4°C.

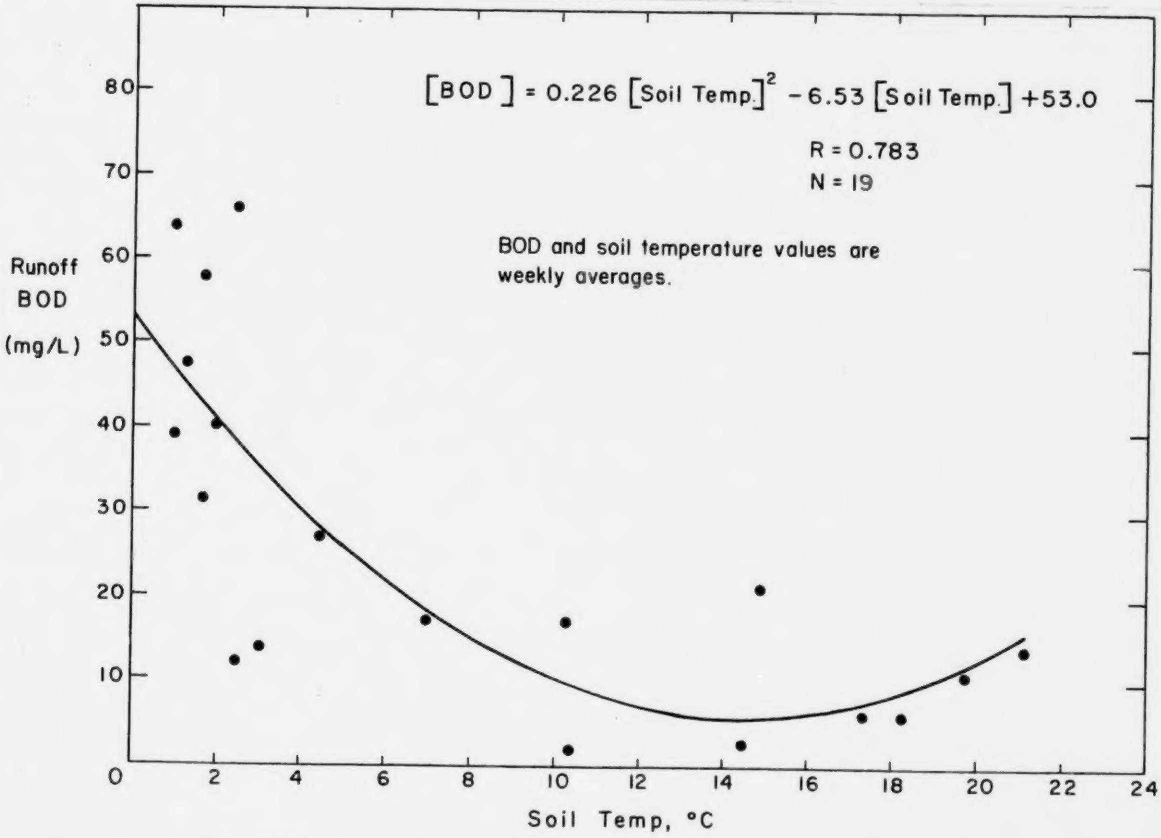

Figure 4. BOD concentration in runoff from CRREL overland flow test site vs. soil temperature.

Also, runoff concentrations exceeded 30 mg/L for a period of 82 days (14 Dec 1977 to 15 Mar 1978). As a result of this study, application of primary effluent during winter in northern areas was not recommended (10). Once the system is shut down for the winter it should not be restarted until spring. In southern areas where soil temperatures may decrease to 4°C or below for only short periods, normal application could be resumed once the cold period is over.

REMOVAL OF VOLATILE TRACE ORGANICS

Results of recent work by Jenkins et al. (11) have shown that overland flow can effectively remove volatile trace organics. Removal efficiencies ranged from 70 to 98% for chloroform to 96 to 100% for toluene. The removal process appears to be volatilization attenuated by incomplete mixing and/or sorption. This appears reasonable considering the large surface area exposed to the atmosphere during the overland flow process.

Removal of volatile organics was found to follow first-order kinetics. Tests conducted with a number of selected organics revealed a good linear

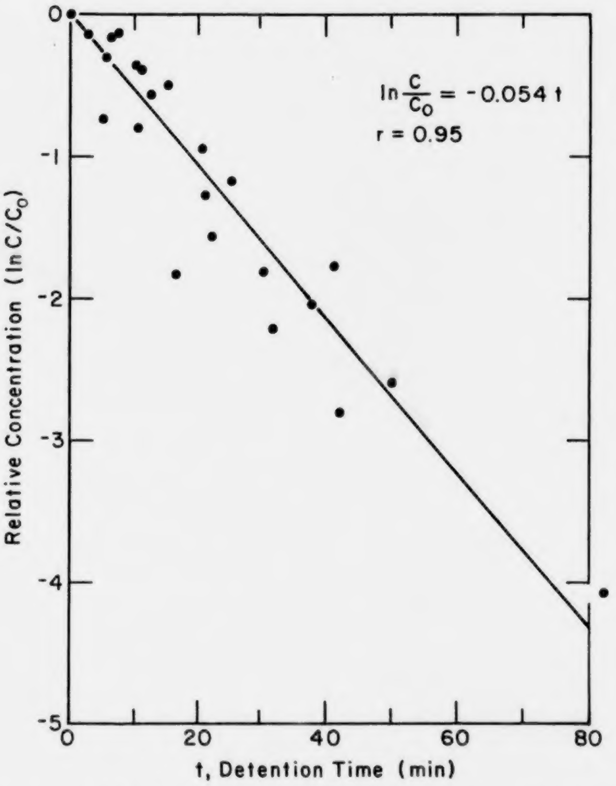

Figure 5. Log of relative concentration of chloroform vs. detention time on CRREL overland flow site.

correlation between the natural logarithm of the relative concentration (C/C_o) and detention time. An example of such a relationship for chloroform removal is shown in Figure 5. The correlation coefficient (r) for the line of best fit was 0.95.

The kinetic rate constants for 14 trace organics obtained in tests conducted at the CRREL overland flow site are shown in Table I. In general, the rate constants for trace organic removal were higher than those for BOD removal. For example, chloroform has an average kinetic constant of 0.054 min^{-1} compared to 0.030 min^{-1} for BOD removal. This difference is further evidence that the removal mechanism is not biodegradation but most likely volatilization. Additional testing is being conducted at other sites to validate these results.

Table I. Kinetic rate constants for removal of selected trace organics at the CRREL overland flow site.

Organic substance	Kinetic rate constant (k) min^{-1}
Chloroform	0.054
Toluene	0.10
Tetrachloroethylene	0.092
1, 1-dichloroethane	0.083
Carbon tetrachloride	0.081
Methylene chloride	0.082
Bromodichloromethane	0.080
Chlorobenzene	0.084
Benzene	0.079
Cyclohexane	0.069
Carbon disulfide	0.12
Diethyl ether	0.080
Acetone	0.052
Ethyl acetate	0.096

SUMMARY

Overland flow is an effective process for removing organics from municipal wastewater. Runoff water quality typically satisfies advanced wastewater treatment requirements. The principal mechanisms responsible for organic removal are sedimentation, filtration, and biochemical oxidation. Trace organics appear to be removed by volatilization. BOD removal efficiency can be predicted using the kinetic and hydraulic relationships developed at CRREL.

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Question (by Mr. Jim Brannan, McGoodwin, William & Yates, Inc., Fayetteville, AR): At what air temperature do you begin to get ice formation?

Response (by Mr. Bouzoun): Last year the development of ice at the toe of the slope began when the temperature dropped to around 15 to 20 degrees Fahrenheit. Ice formation is dependent on the maximum and minimum temperatures, snow cover, and the duration of the cold spell.

Question (by unidentified speaker): Did the impermeable layer have an effect on the flow rate?

Response (by Mr. Bouzoun): I don't know, to be quite honest with you. It is a question of great debate, and there may be no agreement on it. With 6 inches of soil and continuing to apply wastewater--by the time you have applied for four or five hours, you have pretty much saturated the soil. It would seem to me that if the water cannot go down, and if it is moving laterally, as it does, it would have an effect.

PB82-194374

Health Aspects of Overland Flow Treatment

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Technological Resources, Inc.

INTRODUCTION

The public health risks that usually arise in connection with land treatment of municipal wastes are generally the potential of dispersion and/or transmission of disease-causing biological and chemical agents present in the wastewater. The major concerns include: (a) potential contamination of food crops with pathogens or chemical constituents, (b) transmission of pathogens to grazing animals, (c) biological and chemical contamination of groundwater and (d) emission and dispersion of viable aerosols downwind from spray application systems.

Several investigations and reviews have been reported on the fate and public health significance of different biological and chemical contaminants in land treatment systems (1-4). The majority of these reports, however, were mainly concerned with slow rate irrigation or rapid infiltration methods, with relatively few investigations on overland flow systems. Although there are many areas of concern in common with other land treatment methods, overland flow systems are differentiated by limited infiltration and the collection and discharge of the treated wastewater into a receiving water body.

This report will discuss the pertinent health aspects of overland flow treatment. Major emphasis is placed on risks associated with biological constituents since most of the significant chemical contaminants are covered in other presentations in this seminar.

BIOLOGICAL QUALITY OF MUNICIPAL WASTEWATER

Raw municipal wastewater contains significant numbers of a wide variety of pathogenic microorganisms. These generally include bacteria, viruses, and parasites. The levels and diversity of these infectious organisms vary in direct relationship to the prevalence of diseases or carrier state in the community. Table 1 shows the major organisms of health significance in sewage from U. S. communities (2).

The microbiological quality of the wastewater applied in an overland flow system will depend on the preapplication treatment method. Primary treatment by sedimentation or secondary treatment by activated sludge results, in varying degrees of reductions of microorganisms are shown in Table 2 (2). Aerated lagoons or other lagoon systems also result in considerable reductions in pathogenic and indicator organisms. Further microbial reductions are achieved in storage lagoons where they are a required part of the system.

TABLE 1

Major Organisms of Health Concern That May be Present in Sewage from U.S. Communities (2)

ORGANISMS	DISEASE	RESERVOIR (S)
I. PROTOZOA and HELMINTHS		
Balantidium coli	Balantidiasis	Man, Swine
Entamoeba histolytica	Amebiasis	Man
Giardia lamblia	Giardiasis	Man, Domestic & wild animals?
Nematodes		
Ascaris lumbricoides	Ascariasis	Man, Swine?
Ancylostoma duodenale	Ancylostomiasis	Man
Necator americanus	Necatoriasis	Man
Ancylostoma braziliense	Cutaneous Larva Migrans	Cat
Ancylostoma caninum	Cutaneous Larva Migrans	Dog
Enterobius vermicularis	Enterobiasis	Man
Strongyloides stercoralis	Strongyloidiasis	Man, Dog
Toxocara cati	Visceral Larva Migrans	Carnivores
Toxocara canis	Visceral Larva Migrans	Carnivores
Trichuris trichiura	Trichuriasis	Man
Cestodes		
Taenia saginata	Taeniasis	Man
Taenia solium	Taeniasis	Man
Hymenolepis nana	Taeniasis	Man, Rat
Echinococcus gramulosus	Unilocular Echinococcosis	Dog
Echinococcus multilocularis	Alveolar Hydatid Disease	Dog, Carnivore
II. BACTERIA		
Salmonellae (Approx. 1700 types)	Typhoid Fever	Man, domestic & wild animals & birds
Shigellae (4 spp.)	Shigellosis (bacillary dysentary)	Man
Escherichia coli (enteropathogenic types)	Gastroenteritis	Man, domestic animals
III. ENTERIC VIRUSES		
Enteroviruses (67 types)	Gastroenteritis, heart anomalies, meningitis and others	Man, possibly lower animals
Rotavirus	Gastroenteritis	Man, dom. anim.
Parvovirus-like Agents (at least 2 types)	Gastroenteritis	Man
Hepatitis A virus	Infectious Hepatitis	Man, other primates
Adenoviruses (31 types)	Respiratory disease, conjunctivities, other	Man

CONTAMINATION OF FOOD CROPS

Overland flow systems are designed on fine textured soils with low permeability. The applied wastewater results in rapid saturation of the soil and the excess water overflows down the slopes. Food crops that can be used for human consumption can not tolerate these frequent wet soil conditions and can not be grown in these systems. Only water tolerant plants such as Reed Canary or Bermuda grass are suitable as cover crops in overland flow systems. In addition, the cover crop in these systems has to be maintained year-round with minimum disturbance of the soil surface to maintain the smooth sheet flow of the applied wastewater. Food crops are seasonal in nature and harvesting and subsequent cultivation or tillage for planting of a subsequent crop will result in severe disruption of the soil surface that can lead to channeling and the loss of the treatment efficiency of the system. Therefore, the potential of pathogen transmission through the food crop pathway is not possible in overland flow systems.

RISK TO GRAZING ANIMALS

The risk of infection to animals grazing on pastures irrigated with municipal sewage has been suggested by several investigators as a consequence of some reported incidents of disease transmission to dairy cows in England and New Zealand (4, 6).

Overland flow systems, however, are not suitable for animal grazing as pasture land because of the predominantly wet soil conditions. Preliminary results of an experiment conducted at the Paris, Texas system indicated that grazing animals are not compatible with overland flow systems which are specifically designed for wastewater treatment. Allowing the animals to graze in wet fields resulted in compaction of the soil in several locations, thus preventing the reestablishment of the Reed Canary grass. Uneven depressions from the hoofs were formed all over the field resulting in the creation of puddling conditions. The carefully graded and smoothly finished soil surface became almost bare after a few months of grazing and subjected the soil to erosion, effluent chanelling, puddling, and eventual loss of the treatment efficiency. Therefore, overland flow systems can not be used as pasture land because of the inherent characteristics in their design and operation and thus disease transmission to grazing animals from this pathway is eliminated.

The potential of disease transmission to animals feeding on hay crops harvested from overland flow systems treating municipal wastes has frequently been suggested. Pathogenic organisms have been recovered from different types of vegetation irrigated with sewage (4, 7). Survival times ranging between 2 days and up to 60 days for pathogenic bacteria and viruses on vegetation and soils have been reported. Considerable reductions in the number of these organisms is expected, during the drying period prior to harvesting in overland flow systems, as a result of washout by rainfall and die-off from desiccation and ultraviolet radiations. However, it is recommended that hay crops from overland flow systems irrigated with municipal sewage should be stored for at least a 3-month period prior to their use as animal feed.

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FATE OF PATHOGENS IN OVERLAND FLOW SYSTEMS

Virus Removal

Removal of viruses from wastewater by soils has been studied by several investigators both in batch systems and field investigations (2, 3, 4, 5, 8, 9). Almost all of these studies were primarily concerned with rapid infiltration systems because of the potential of groundwater contamination.

The removal and fate of viruses in overland flow systems is significantly different from that encountered in other land treatment methods. The permeability of the soils restricts the infiltration of the wastewater thus preventing any significant downward movement of the viruses into the deeper layers of the soil. Most of the applied wastewater flows over the soil down the slopes to the effluent collection ditches.

The only study on the fate of viruses in overland flow systems was conducted by Schaub et al. at the Ada, Oklahoma 36-m experimental plots (10). Indigenous enteric virus removals from raw, primary, and secondary municipal wastewater, applied at rates ranging from 15 to 40 cm per week, were found to be greater than 85 percent for raw and secondary treatment plots. Primary treatment wastewater plots exhibited more variability and relatively less removals ranging between 68 to 80 percent (see Table 3). Batch adsorption studies indicated that soils from the plots receiving secondary wastewater and subsurface soils (2-8 cm depth) were more effective in virus adsorption than surface soils from the other wastewater treatment plots. The difference in adsorption was suggested to be due to competitive adsorption between soluble organic matter and the viruses for the available adsorption sites on the surface of the soil particles.

Removal of tracer bacteriophage f2 seeded into the applied wastewater was also studied at various points along the length of the plots. Modest tracer virus removals ranging between 30-60 percent were observed. In general, over half of the total removals occurred in the upper portion of the slopes regardless of plot age or type of wastewater applied.

It was also revealed that the f2 virus applied to the soil plots was able to migrate down the slopes (36m) and equilibrate throughout the application cycle within 50-90 minutes after application. No obvious difference in migration could be attributed to the age of the plots or the quality of the wastewater (see Figure 1). Generally, the viruses accompanied the wastewater through the treatment slopes at the same flow rate in essentially plug flow characteristics especially at the higher application rates.

The virus was cleared from the plots slowly after termination of seeding to the wastewater and more than 4 hours of flushing were required before the virus level in the effluent became equilibrated at new higher background levels (see Figure 2). This indicated that some viruses were retained through pooling, flow channelization, temporary adsorption, or filtration on the soil surface. The higher background level was suggested to be due to possible regrowth of indigenous coliphage or that some slow

TABLE 3

Percent Enteric Virus Removal by Overland Runoff[a](10)

Sample Day	Raw Wastewater	Primarily Treated Effluent			Secondarily Treated Effluent		
	Plot 3 (20 cm)[b]	Plot 2 (20 cm)	Plot 4 (15 cm)	Plot 5 (20 cm)	Plot 1 (40 cm)	Plot 6 (20 cm)	Plot 7 (40 cm)
1	-	86.0	> 94.0	90.8	94.0	88.0	> 94.0
2	-	39.4	76.8	76.8	94.0	82.3	64.7
3	-	81.3	95.3	76.8	> 94.0	94.0	> 94.0
4	-	72.1	95.3	72.1	88.3	94.0	94.0
8	-	> 94.0	> 94.0	72.1	> 94.0	94.0	> 94.0
11	77.0	67.3	58.1	86.0	94.0	82.3	88.3
15	-	72.1	58.1	53.4	64.7	88.3	76.0
24	91.5	21.0	53.4	62.9	82.3	94.0	88.3
25	95.1	76.8	95.3	25.4	88.3	94.0	76.0
Avg. % Removal	87.9	> 67.8	> 80.0	68.5	> 88.2	90.1	> 85.5

Average pfu/liter at plot influent: Raw wastewater - 137.8; Primarily treated wastewater - 35.8; Secondarily treated wastewater - 28.3.

[a] Calculated from virus in plot effluents as a % of plot influent virus levels.

[b] Centimeters of wastewater applied to plots weekly.

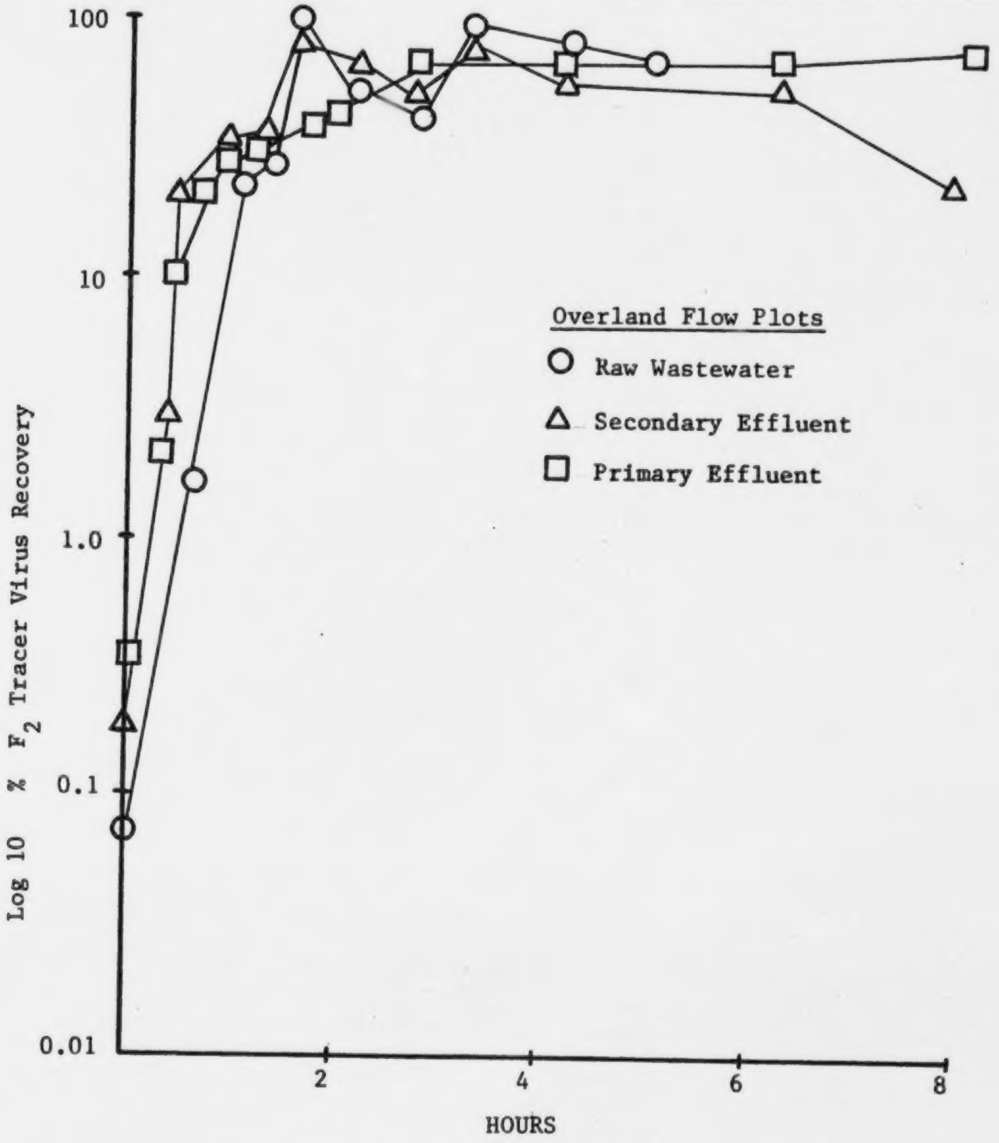

FIGURE 1. Tracer f2 Virus Recovery from Overland Runoff Plot Effluents

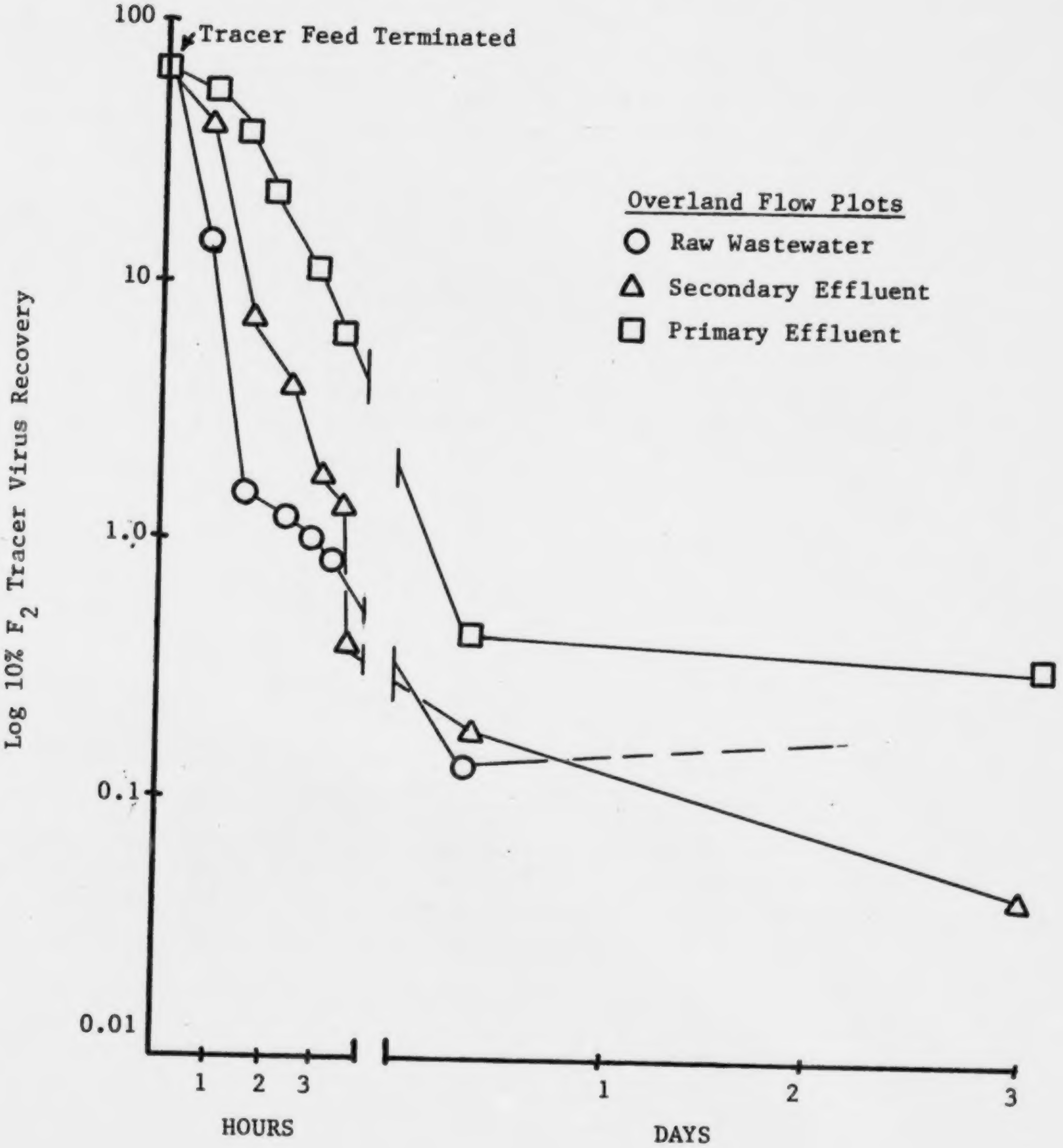

FIGURE 2. Tracer f2 Virus Clearance from Plot Effluents after Termination of Wastewater Seeding

virus releasing mechanism was operating.

Subsurface penetration of the virus was limited, since only 12.7 percent of surface virus concentration was observed at 2 cm depth and 1.4 percent of the surface concentration was found at 8 cm depth on plots receiving primary or secondary treated effluent.

In summary, the present information indicates that overland flow systems are capable of removing 70-90 percent of enteric viruses from municipal wastewaters. However, the removal of viruses seems to be species specific since lower removals were obtained with coliphage f2 virus. Further investigations are needed to fully evaluate removals of different viruses on overland flow systems. The virus removal in these systems was suggested to be provided by the mechanisms of surface settling, filtration, biological metabolism, predation by soil microflora, toxicity of the soil, photochemical reactions, and thermal inactivation. Underground water contamination by viruses is unlikely in overland flow systems because of the low permeability of the soils.

Indicator Organisms Removal

The diversity of the pathogenic bacteria that may be present in domestic wastewater makes their isolation and identification in a single or simple test technically impossible. Because of the abundance of the coliform group of organisms in a human intestine, they were selected as indicators of biological safety of waters. Several studies and reviews on the fate of pathogenic and indicator organisms in slow rate or rapid infiltration systems indicated substantial removals due to physical filtration in the upper layers of soils (2, 4, 5).

Removal of indicator organisms in overland flow systems, however, follows a different pattern from other land treatment systems because of the treated runoff that is discharged into surface waters. Thomas et al. reported that removals of 95 percent for total coliforms and 90 percent for fecal coliforms were achieved in the overland flow experimental plots in Ada, Oklahoma treating raw comminuted municipal sewage (11). However, the final numbers were generally higher than 10^4/100 ml. A more detailed study by Hunt et al indicated a seasonal response of fecal coliform removal on an overland flow system treating lagoon treated wastewater (12). A significant increase in numbers was absorbed in the treated effluents during the summer weather which often exceeded the levels in the applied wastewater. This indicated that fecal coliforms were capable of growth in the soils.

Recently Hoeppel et al. conducted a more comprehensive evaluation of the fate of fecal coliforms in the overland flow systems in Utica, Mississippi (13). The seasonal variation in the removal of fecal coliforms previously observed by Hunt was confirmed (12). During the spring and summer, higher fecal coliform levels in the runoff than in the applied lagoon wastewaters were observed. Proliferation of indigenous fecal coliforms in the soil of the genus Klebsiella and Enterobacter contributed to the increased coliform levels in the runoff. Utilizing E. coli as a better indicator organism of fecal pollution, the same seasonal variation was observed. The increased counts in the runoff during the hot summer and above freezing fall period was attributed to the high level of suspended solids in the wastewater which acted as nitches for the survival and growth of E. coli and other coliforms and provided protection from harsh weather conditions. The lowest effluent fecal coliform counts were encountered during the late winter and early spring period. The continued freezing and thawing of the treatment plot surfaces, combined with low influent wastewater numbers, appeared to be responsible for this trend.

Excellent fecal coliform removal in excess of 95 percent was observed when the wastewater was continuously applied, at low rates for 24 hours versus intermittent application for 6 hours each day on a 5 day/week (see Figure 3). Under the continuous flow conditions, a conspicuous biological layer consisting mostly of diatom tests, was established. In addition, high population of ciliate protozoans were observed in the field suggesting that predation by these organisms was partly responsible for fecal bacterial decline. The organic layer appears to have acted to increase the residency of the overland flow and served as an effective bacterial filter which provided for easy scavenging by the predator organism. The continuous flow conditions, however, were not favorable for good grass growth and may promote odor conditions if stronger wastewaters are applied. Probably intermediate flow conditions would be more favorable.

The above seasonal variation in the coliform levels and the response to continuous application conditions relates to the treatment of lagoon-treated wastewater. Similar behavior has not been reported for treating primary or conventional secondary treated wastewater and further investigations on such types of wastes are certainly needed.

HEALTH RISK OF VIABLE AEROSOLS

One of the most controversial potential health hazards associated with land treatment with sprinkler application is the emission and spread of airborne aerosols containing viable pathogenic microorganisms. This same concern has also been raised in connection with wastewater treatment by conventional secondary treatment processes as early as the beginning of this century, and interest in this subject still continues.

Aerosols from Conventional Treatment Processes

Recently Hickey and Heist (14, 15) presented a review of field investigations and related literature on the health significance of airborne microorganisms from wastewater treatment processes. A summary of the significant findings in this survey as related to conventional wastewater treatment plants is presented here in order to put the aerosol problem in perspective. The major findings indicate that many types of bacteria are emitted to the air from wastewater during almost any stage of collection, treatment, or disposal. These airborne microorganisms remain viable and airborne for a considerable distance downwind. Significantly higher numbers of airborne bacteria were reported recovered from downwind samples than from upwind or other control samples (see Table 4). Much larger numbers were recovered downwind from aerated sources such as

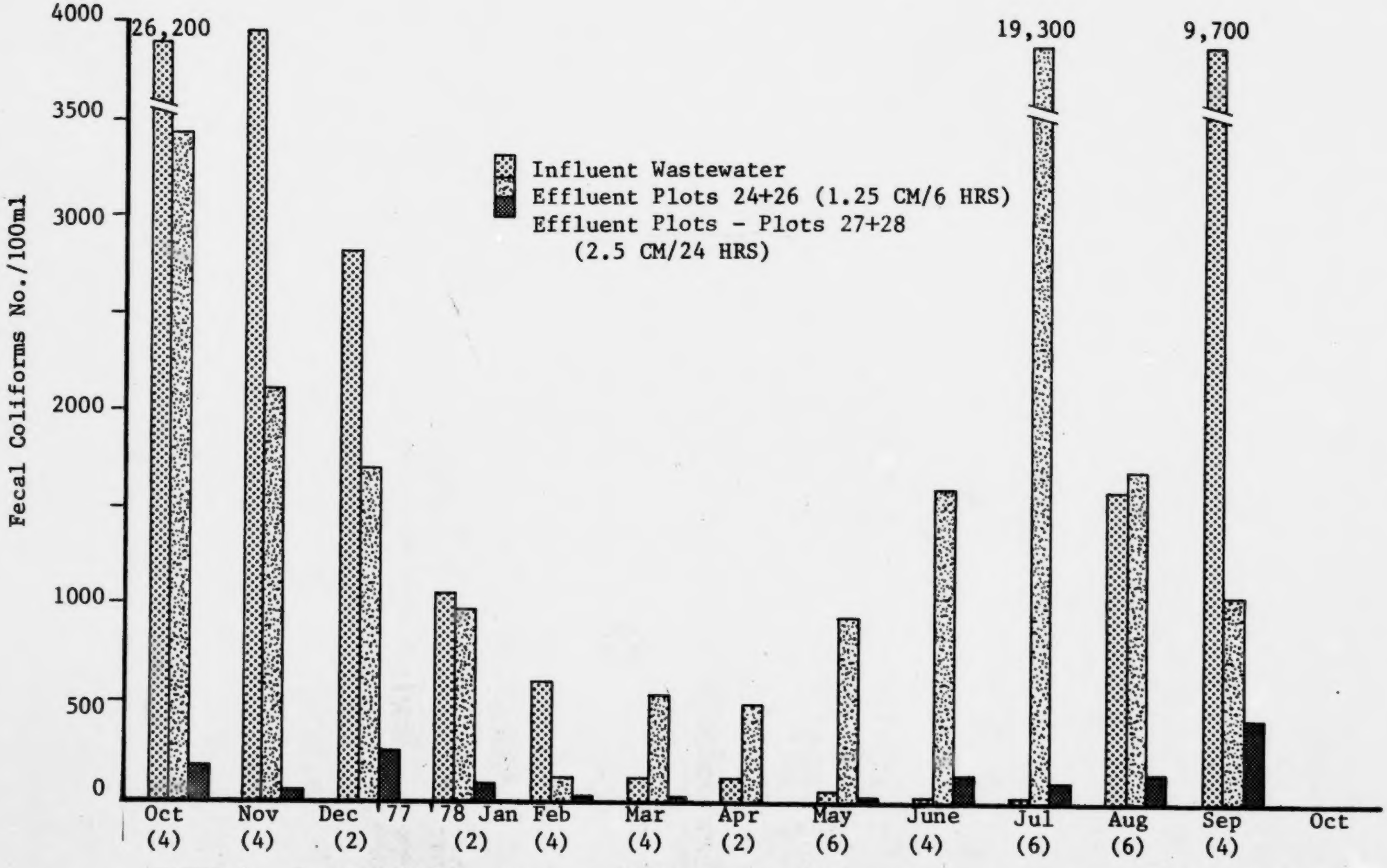

FIGURE 3. Fecal coliform counts in Utica overland flow plot samples receiving intermittent or continuous wastewater at different flow rates. (Note: Replicate numbers are given in parentheses.)

TABLE 4

Summary of Viable Aerosol Levels
for Wastewater Treatment Plants (15)

Distance		Viable Particles/Cu m
Immediately downwind		320-30,700 (solid media) 41,200 (liquid media)
300 ft.	(1.4 m)	0-1,100
1,180 ft.	(360 m)	48
2,300	(700 m)	529
900	(275 m)	129
2,640	(800 m)	108
4,230	(1290 m)	3
Upwind	< 212-3040	

activated sludge and trickling filter plants, than from nonaerated sources, such as grit chambers. A large variety of individual genera and species were identified from recovered particles. These included several pathogenic genera and species (see Table 5). The survival rate of intestinal bacteria was reported to be much lower than for other bacteria normally occurring in the air. Species selective aerosolization of bacteria from the surface of liquids has been demonstrated. However, information on virulence of bacterial aerosols generated from wastewater is sparse. Several investigators seemed to equate the presence of pathogenic bacteria with virulence. The recovery pattern was similar in each study; there were relatively high counts per unit volume near the source and much lower counts as downwind sampling distance increased. Downwind viable aerosol concentrations diminished to upwind concentrations within a few hundred feet of the source.

Particle sizes of the viable aerosols generated from aerated wastewaters were in the human respirable range. The geometric mean aerosol diameter ranged from 4.2 to 4.5 μm both for the daytime and nighttime sampling conditions at various downwind distances.

The principal variables affecting survival and dispersion are die-off, deposition, and diffusion. In general, the observed pattern was high initial viable aerosol decay rate (that is reduction in viable aerosol concentration) followed by a much lower decay rate. The initial decay rate was attributed mainly to organism die-off from stress of droplet evaporation, there being

TABLE 5

Microorganisms Assayed and Identified in Field Studies of Viable Bacterial Aerosols from Wastewater (15)

Microorganisms Assayed	Number of Investigations
Type of Assay	
Total count	10
Index organism count	11
Identification	
Escherichia coli	6
Aerobacter sp.	4
Coliforms	11
Klebsiella	4
Providence	1
Shigeila	1
Salmonella	3
Bacillus typhosus	4
Staphylococcus aureus	1
Streptococci	1
Hemolytic strep.	1
Mycobacterium	1
Acid-fast bacilli	1
Enterobacteriaceae	1
Proteus	3
Serratia marcascens	1
Pseudomonas	2
Bacillus subtilis var. globigii	1
Other	6
Organism source	
Natural aerosol	3
Seeded tracer	4

insufficient exposure time for factors such as solar radiation to account for the die-off. Die-off and horizontal diffusion were found to be the dominant factors in the depletion of the variable aerosol. The deposition of particles is important very close to the source but is less important and a nearly constant depletion factor farther than 35 feet from the source. No plume rise effect of the viable aerosols was found, and higher downwind recoveries at higher wind speeds were reported by several investigators. The reported effects of relative humidity on viable wastewater aerosol survival are not conclusive; some investigators have observed increased aerosol survival at higher relative humidities, but others have found no effect. Aerosol recoveries in darkness were generally higher than daytime recoveries.

Aerosols From Land Treatment Systems

The generation and subsequent dispersion of microbial aerosols downwind from land treatment systems utilizing sprinkler application methods have been the subject of several studies and reviews in recent years. The first U.S. field study that demonstrated the airborne spread of microorganisms from land application of wastewater was published by Merz in 1957 (16). Coliforms were recovered only downwind from a sprinkler spraying treated wastewater onto a golf course. More recently, investigators from the U.S. Army Medical Bioengineering Research and Development Laboratory published a series of investigations on bacterial aerosols from spray irrigation systems including the development of a model for the prediction of pathogenic concentration downwind from a spray source (17-20). A summary of the most recent study on the dispersion of bacterial aerosols resulting from land application of chlorinated, ponded wastewater by spray irrigation is presented here (21).

The wastewater was applied by 96 sprinkler heads covering an area of 2.1 hectare (5.2 acres). Aerosol samples were placed at distances of 30, 50, and 200 m from the most downwind row of the sprinkler heads. The samplers were placed on 1.7-m stands and several runs were conducted with the samplers raised to elevations of 4.6 and 9 m on a tower located 50 m downwind.

The results of this study indicated that the background density of airborne bacteria-bearing particles ranged from 23 to 403/m^3, with a mean of 110.8/m^3. At the 21-30 m distance, total aerobic bacteria-bearing particles varied from 46-1582/m^3 above background (see Table 6). The mean value for all runs at this sampling distance was 485/m^3 above background. At the 41-50 m distance, values ranged from 0-1429/m^3 above background with a mean for all runs of 417/m (85% of 21-30 m mean). At the 200 m distance, observations were not always above background levels, and the highest value observed was 223/m^3 above background. The mean observation above background for all samples at this distance was 37/m^3 (7.6% of 21-30 m mean).

A steep decline in bacterial aerosol density was observed upon elevation of samplers to 4.6 m or 9 m above the ground (see Table 6). Values at 4.6 and 9 m elevations averaged 30 percent and 5 percent respectively of those at 1.7 m.

Estimates of median particle diameter and the percentage of particles with diameters in the range 1 to 5 μm are as presented in Table 6. The data clearly indicate that the background bacterial aerosol was larger in particle size than the aerosol arising from applied wastewater. Approximately 66 to 78 percent of the downwind bacteria-bearing particles were between 1 and 5 μm in diameter, the approximate range of efficient pulmonary deposition. Biological decay or die-off immediately downwind from the sprinklers was rapid and was estimated to be in the range of 30 to 50 percent.

Coliforms were a small part, less than 1.0 percent of aerosol populations, presenting scarcely measurable increases above background levels. The _Klebsiella_ group comprised approximately 0.1 percent of wastewater bacteria. Thus, a mean aerosol level of 485 cfu*/m^3 at 30 downwind suggests a _Klebsiella_ aerosol strength of 0.5 cfu/m^3.

*cfu - Colony forming unit

TABLE 6

Median and Quartile Particle Diameters and Percentage of Particles 1 to 5 μm in Diameter, Compared to Mean Net Aerosol Concentration (21)

	Mean Net Aerosol Conc. cfu*/m^3	Quartiles Lower	Quartiles Middle	Quartiles Upper	% 1-5 μm
Runs 1-5 15-25					
1st Row	490	1.58	2.46	4.12	78
2nd Row	395	1.55	2.44	4.15	76
200 m	37	1.60	3.01	5.50	67
Upwind	0	2.03	4.15	7.32	48
Runs 7-14					
1st Row	473	1.82	2.82	4.40	75
2nd Row	434	1.88	2.87	4.74	73
4.6 m	125	1.92	3.00	5.10	68
9.0 m	20	1.70	3.03	5.30	66
Upwind	0	1.97	4.59	7.50	49

*cfu - Colony forming unit

Sorber indicated that the presence of Klebsiella in airborne aerosols from spray irrigation systems was of public health significance because of their capability of producing respiratory infections in humans (18).

Aerosols in Overland Flow Systems

There is no available information in the literature on the levels of microbiological aerosols from overland flow systems utilizing sprinkler application. As indicated earlier, all the studies were conducted on slow rate irrigation systems where the aerosol samplers were placed immediately downwind from the sprinkler heads, outside the area wetted by the spray. However, in overland flow systems the sprinklers are placed at the upper end of a sloped area where the wastewater is allowed to flow across the land surface for a distance of about 150 to 200 feet before discharging into a collection ditch at the bottom of the slope. During sprinkling, the entire sloped area, which is an integral part of the treatment system, becomes wet with limited or no access to field workers or others. Considerable reduction of microbiological aerosols formed at the sprinkler heads is expected at a distance of 150 to 200 feet downwind at the bottom of the slopes due to deposition, die-off, and diffusion. The provision of a buffer zone of about 100 feet will allow an additional margin of safety for the reduction of airborne aerosols beyond the property line. Therefore, these systems possess the unique feature inherent in their design that minimizes the risk of exposure to biological aerosols.

The designers of overland flow systems, however, should be aware of the potential health risks associated with airborne aerosols and, therefore, should orient the sprinkler lines, if topography of the land allows, perpendicular to the prevailing wind so as to minimize the carry-over of aerosols beyond the perimeter of the treatment system.

Significance of Aerosols

The striking similarity between the levels and types of airborne organisms recovered downwind from land treatment systems and those from conventional treatment systems can not be overlooked. The obvious conclusion is that any type of wastewater treatment system, whether conventional or land treatment, poses the potential of emissions of many types of microorganisms that remain viable for some distances downwind. Whether there is a public health hazard or not is not conclusive. Several investigators equated the presence of pathogenic bacteria in aerosol with virulence, and inferred the potential of causing respiratory or other diseases in plant workers or nearby residents. On the other hand, recovery of small numbers of these organisms was considered of no significant health risk by others.(15).

Epidemeological evidence supporting a health hazard from microbial aerosols from wastewater treatment is certainly lacking. The U.S. Environmental Protection Agency (EPA) is currently sponsoring a study by the University of Cincinnati Medical Center aimed at the assessment of the health risks of populations occupationally exposed to wastewater collection and treatment. The study also includes the determination of the health effects associated with the dispersion of aerosols generated by the activated sludge and land treatment system (22). Preliminary results of a seroepidemiologic study by this group indicated that no significant difference in viral infection rates was observed between sewage treatment plant workers and highway maintenance workers (control group). Also, there was no significant difference in immenoglobulin levels between the two groups. Final results of this study have not yet been published.

The question of dose-response for the recovered airborne pathogens has not been adequately addressed in these investigations. From the data on Klebsiella recovery near activated sludge aeration tank, Ledbetter et al. calculated that an employee would inhale, at most, 105,600 Klebsiella/month (23). They considered the risk of infection minimal since it was found that 850,000 inhaled Klebsiella pneumoniae caused infection in squirrel monkeys but 730,000 did not. More recently, Sheikh-ol-Eslami assessed the risk to human health from aerosols generated from sprinkler irrigation of secondary treated effluent (24). He indicated that a major factor influencing the health risk associated with aerosols is the concentration of pathogenic organisms in the sprayed effluent. Assuming pathogen concentration in the sprayed effluent of seven per liter, and ignoring die-off during aerosolization by the sprinklers, the probability of inhaling a viable pathogen during an eight-hour period at a distance of 15 m (50 ft.) from the sprinklers was computed to be approximately 1 in 86,000. The following assumptions and procedure were followed to determine the probability. From the results of field measurements of aerosol counts in the various particle size range, it was estimated that 0.86×10^{-6} liter of aerosols in one cubic meter of air were contributed at a distance of 15 m from the sprinklers. Assuming that the human nose captures 50% of the particles with a random orientation; that a wind speed of 0.75 to 2.75 m/s prevails; that breathing rate of 4.8 m^3 of air in eight hours occurs; and that 80% of the aerosols are deposited in nasopharyngeal regions, the probability of inhaling one pathogen during an eight-hour exposure is:

$$P = 0.86 \times 10^{-6} \times 7 \times 0.5 \times 0.8 \times 4.8 = 1.16 \times 10^{-5}$$
(or 1 in 86,000)

The dose-response relationships of the specific pathogen will determine the risk of becoming ill as a result of such exposure. For example, if it takes 10,000 pathogens before an individual becomes clinically sick from inhalation of microorganisms in the aerosol, then the risk of exposure will become 1 in 860,000,000 (24).

ODOR RISK

The potential of the production of objectionable odors in overland flow systems is minimal since the treatment is essentially achieved by aerobic processes. The wastewater is effectively aerated as it contacts the ambient air during spraying, and as it flows in thin sheets over the soil, rapid oxygen transfer also takes place at high rates thus maintaining aerobic conditions in the upper water layer. In addition, during the rest periods, aerobic conditions are restored by rapid diffusion of the oxygen from the air through the soil pores as the soil dries out.

The absence of odors in overland flow systems treating raw or primary domestic sewage has been reported by the EPA Research Laboratory in Ada, Oklahoma and substantiated by reports in many similar land treatment systems across the country.

The first effort to quantify odor emissions from overland flow systems was recently conducted at Campbell's Paris, Texas plant (25). Surface odor emission rate (SOER) measurements were conducted using a Direct Reading Olfactometer (DRO). The instrument is used to determine the maximum dilution threshold odor concentration (MDTOC). A human subject is provided a constant background of carbon-filtered air with periodic doses of increasing fractions of odorant-containing air. The MDTOC is reached when the subject identifies the presence of the odor at least half of the time.

The quantitative flow measuring portion of the system is portable. It is mounted on a backpack and carried by the subject to the odor source. A battery pack carried by the operator provides a portable power supply and allows measurements at various locations. A sample probe is held by the subject within the region of the odor source. The operator varies air flow rates to determine the maximum dilution of the odorant-containing air which the subject can detect at least half of the time.

The apparatus used for measuring SOERs contains a hood which serves to isolate a known surface area. By pumping a constant rate of carbon-filtered air through the hood, an equilibrium odor concentration is established inside which depends on the SOER from the isolated liquid surface. After this equilibrium concentration is reached, the odor strength of the hood air stream is analyzed with the DRO. The air pump used to purge the hood is an odor-free teflon lined diaphragm pump. This is necessary because the pump exhaust is used as the sample source for DRO measurement.

The SOER magnitude is calculated as follows:

$$\text{SOER} = \frac{Q_h c}{A_h}$$

where,

Q_h = hood air flow rate, scfm

A_h = liquid surface area, ft^2

c = DRO measured odor concentration, ou/cf

The SOER values for the raw wastewater at the pumping station are presented as a frequency distribution in Figure 4. The SOER magnitude ranged from 2.0 to 12.5 ou/min/sf with the median value being approximately 6.5 ou/min/sf. The wastewater was characterized as having a "weak soup" odor.

Measurements were completed on the spray fields immediately after loading and resting and on the downhill sheet flow treatment area. SOER magnitudes were also measured in the collection ditches, ponded areas, and on grasses not receiving loading from wastewater. These results are presented as a frequency distribution in Figure 5.

Measured SOER magnitudes were low with the highest value being 6.25 ou/min-sf. Of significance to note is that background odors on areas receiving no wastewater had SOER magnitudes of approximately 2 ou/min-sf. Only 3 of 15 measurements had SOER magnitudes above background levels. In the absence of a nearby sprinkler discharge, no ambient odors were detectable, indicating that the wetted areas were not contributing to downwind odors. Apparently the sprayed wastewater does not contribute to ambient odors once it enters the active biological overland flow treatment area.

The treated wastewater entering collection ditches and in some cases ponded areas did not contribute to ambient odors. The SOER magnitudes were not above background SOER magnitudes.

A number of measurements of ambient air odor concentration downwind from the sprinklers inside the site were also conducted. The results are summarized in Table 7. The odor concentration ranged between less than 1 to 8 ou/cf with a single reading at 10 ou/cf. No measurable odor was detected at the property line.

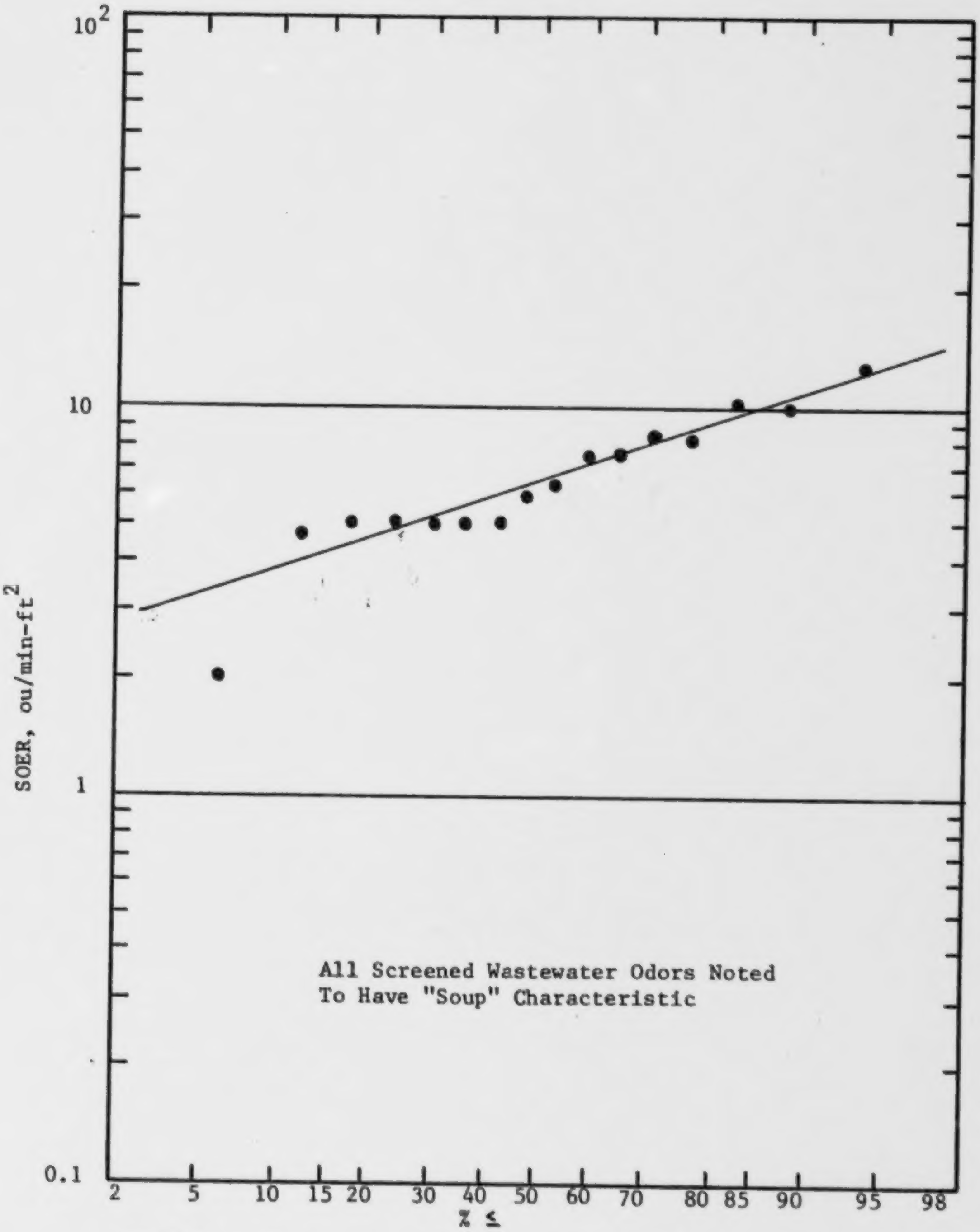

FIGURE 4. Wastewater SOER from Screening Room, Paris, Texas

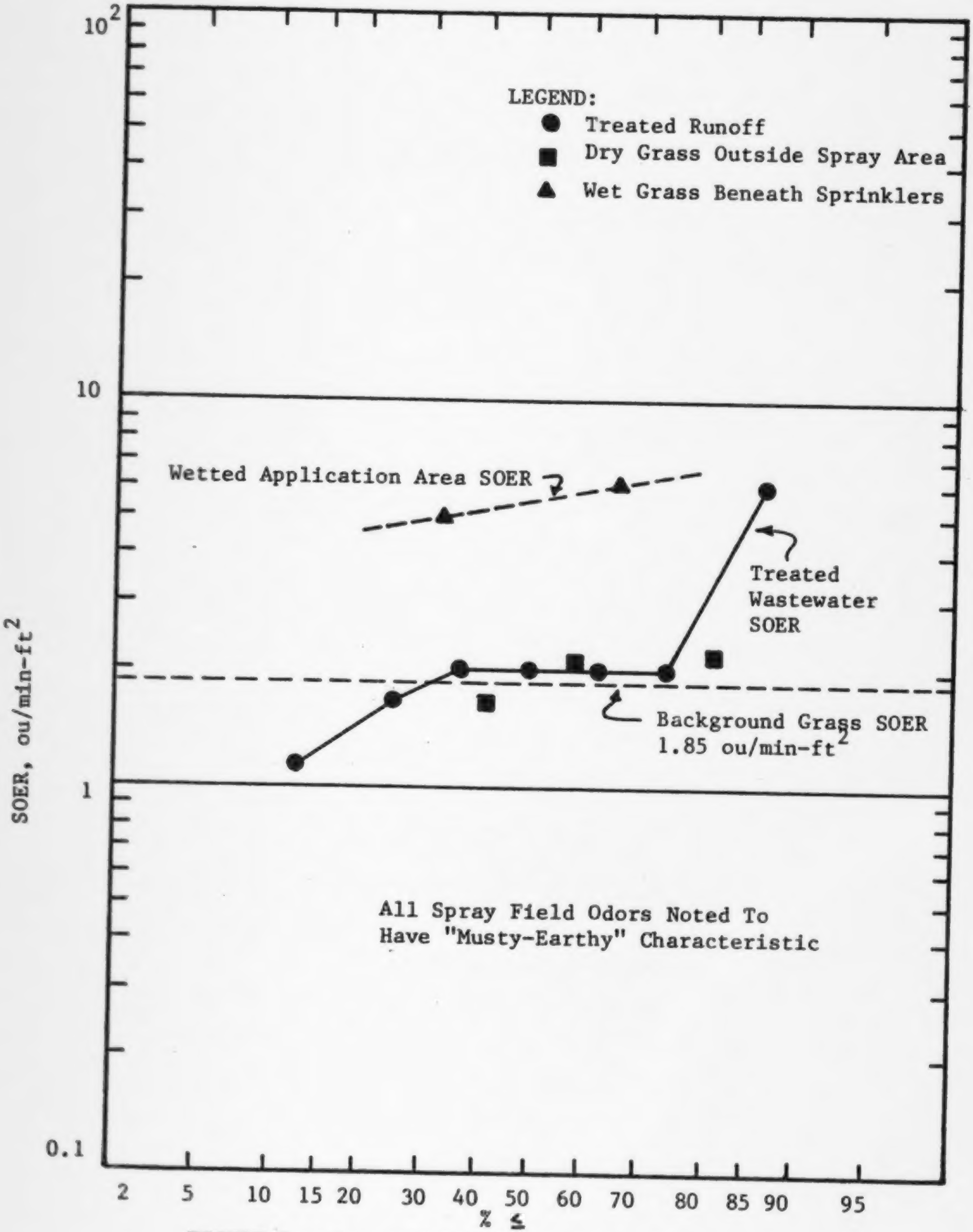

FIGURE 5. Spray Field SOER, Paris, Texas

This study illustrates that odor risk from overland flow systems are virtually nonexistent. The predominantly aerobic conditions in the system prevent the development of anaerobic conditions that could result in the creation of undesirable odors.

TABLE 7

Ambient Odor Concentration Measurements (25)

Date	Time	Odor Concentration (ou/cf)	Comments
8/29	13:40	7-8	W-18 @ Road
	17:00	10	W-18 @ Road
	18:21	2	W-18 @ Road
	22:35	6	W-24 @ Road
	20:10	4	W-24 @ Road
8/30	13:50	1	W-18 @ Road
	20:18	1	W-24 @ Road
	21:00	1	W-15 @ Road

SUMMARY AND CONCLUSIONS

1. Overland flow treatment systems do not pose a health risk of disease transmission via food crops for human consumption or to grazing animals because the prevailing wet soil conditions exclude the utilization of the land for either purpose.

2. The removal efficiency of overland flow systems for pathogenic organisms such as viruses and indicator organisms is comparable to that which is achieved in conventional secondary treatment systems without chlorination. Disinfection may be required, however, if the receiving stream water quality warrants higher biological quality effluent.

3. The relatively long treatment slopes in the overland flow systems provide a reasonable distance downwind from the sprinkler heads to allow reduction in microbial aerosol that are generated in sprinkler application systems. Additional buffer zones will provide an extra margin of safety.

4. There is a striking similarity between the biological aerosols generated during sprinkler application of wastewater and those from other conventional secondary treatment processes such as activated sludge or trickling filters. Yet, there is no epidemiological evidence of a health hazard from biological aerosols generated during any wastewater treatment process. Further investigations are needed to assess the dose-response relationship of microbial aerosols.

5. There is practically no odor risk from overland flow systems because of the maintenance of aerobic conditions in properly operated treatment systems.

6. Site selection for overland flow systems treating municipal wastewater is of primary importance in minimizing most of the potential health risks. Sites should be selected at reasonably remote distances from residential areas and should be of limited access to the general public.

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Question (by Mr. Ted Stackley): Was there any evidence that there was a pathogen transmission to cattle from the crop?

Response (by Dr. Aly): There was no transmission of pathogens originating from the wastewater. There were problems because of the extremely wet conditions. Although I am not too familiar with animal diseases, I know that some of the cattle developed hoof infections due to the extremely wet conditions.

Question (by Mr. Tom Ellison): In reference to pathogens, do you think that the grass crops are suitable for use as livestock feed?

Response (by Dr. Aly): They are certainly suitable, to the extent that they are free of pathogens. If crops are heat processed to destroy pathogens, there is obviously no concern.

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Removal of Nitrogen and Phosphorus by Overland Flow

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INTRODUCTION

Implementation of the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500), passage of the Clean Water Act of 1977 (PL 95-217) and incentives for the use of innovative and alternative technologies in the Federal Construction Grants Program of the U.S. Environmental Protection Agency have resulted in a renewed interest in the development of land application as a major management alternative for the effective treatment of municipal wastewater. The principal land treatment processes widely used in the United States and elsewhere include slow infiltration, rapid infiltration, and overland flow application. Other processes, which are less widely used and generally less adaptable to large-scale use than the three major ones, include wetland and subsurface applications. The land requirements, design characteristics, hydraulic loadings, and soil properties of these treatment systems are discussed in a recent U.S. EPA manual (1). Water pollution parameters considered important in the renovation of wastewaters by land treatment include biochemical oxygen demand, suspended solids, nutrients heavy metals, algae, organics, and pathogens (1). Significant research efforts have been made in the last decade by the U.S. EPA and the U.S. Army Corps of Engineers to understand the mechanisms of various renovation processes and consequently to control these mechanisms by design and operation to make land treatment a cost-effective and reliable technology. This National Seminar on Overland Flow Technology was organized to assess developments in the use of overland flow treatment systems as an effective method of municipal wastewater renovation.

In overland flow land treatment, also called grass infiltration, wastewater is applied at the upper reaches of sloped lands, either by flooding or spray irrigation, and allowed to flow across the vegetated surface. The wastewater is renovated by physical, chemical, and biological means as it flows in a thin film down the relatively impermeable slope. Contrary to slow-rate and rapid infiltration, there is relatively little percolation involved due to impermeable soil or a subsurface barrier to percolation, thus minimizing the possibility of ground water contamination. The major objectives of overland flow systems are (1) to achieve secondary or better effluent quality from screened primary-treated, or lagoon-treated wastewater; and (2) to achieve high levels of nutrient and BOD removal comparable to conventional advanced wastewater treatment from secondary-treated wastewater. A survey of the composition of wastewaters applied to different overland flow treatment systems presented in Table 1 indicates that most municipal wastewaters contain significant concentrations of nitrogen and phosphorus. These two nutrient elements can be serious pollutants if discharged to surface waters. In recent years, considerable research has been conducted to investigate loading rates for different soil types, frequency of application

Table 1. Composition of municipal wastewaters applied to overland flow treatment systems.

Parameter mg/ℓ	Overland Flow Site									
	Melbourne, Australia (2)[a]	Pauls Valley, Oklahoma (3)		Ada, Oklahoma (4)			Easley, South Carolina (5)		Hanover, New Hampshire (6)	
	Primary Wastewater	Raw Wastewater	Secondary Wastewater	Raw Domestic Wastewater	Primary Effluent	Secondary Effluent	Raw Wastewater	Lagoon Effluent	Primary	Secondary
NO_3^--N	0.1	0.01	0.1	—	—	—	6.0	2.4	0.5	5.1
NO_2^--N	0.1	—	—	—	—	—	—	—	—	—
NH_4^+-N	26.1	16.5	13.5	—	—	—	19.4	1.0	33.1	27.3
Org-N	25.0	7.3	3.9	—	—	—	29.1	4.3	—	—
Total N	51.3	23.8	17.5	34.5	19.0	15.3	—	—	36.6	33.5
PO_4^--P	5.1	—	—	—	—	—	6.6	3.0	—	—
Total P	7.8	8.3	6.3	8.1	7.3	6.6	8.9	3.8	6.3	5.9
TOC	336	—	—	90	31	16	31.1	23.1	89.2	57.0
BOD	550	130	16.2	—	—	—	—	—	85.3	53.2
pH	6.9	7.1-8.0	7.2-9.0	—	—	—	—	—	7.4	7.5

[a] Numbers in parentheses refer to the references listed at the end of the paper.

for maximum nutrient removal, mechanisms involved in transformation, retention, and movement in the soil, and management practices for controlling nitrogen and phosphorus behavior in an overland flow treatment system. A brief review of the recently published data on the removal of nitrogen and phosphorus during overland flow is presented in this paper. The topics discussed in this paper are:

- Efficiency of nitrogen and phosphorus removal
- Nitrogen removal processes
- Phosphorus removal processes

EFFICIENCY OF NITROGEN AND PHOSPHORUS REMOVAL

Untreated municipal wastewaters generally contain total nitrogen concentrations in the range of 20 to 85 mg N/ℓ, of which 12 to 50 mg N/ℓ may be ammonium-nitrogen and the remainder present as organic-nitrogen (1). Nitrate- and nitrite-nitrogen is generally present in trace amounts. Total phosphorus generally varies from 6 to 20 mg/ℓ with the ratio of inorganic phosphorus to organic phosphorus fluctuating from 1:1 to 2:1 (1). A recent review of data indicates that preapplication treatment of raw wastewater, using primary sedimentation, will reduce BOD and suspended solids, but does not greatly affect nitrogen and phosphorus concentrations (1). Secondary treatment in oxidation ponds, aerated lagoons, or other biological processes may reduce nitrogen and phosphorus concentrations but the removal efficiency is variable. Data on the composition of raw and pretreated wastewater summarized in Table 1 indicate that the composition of wastewater is very site-specific. For example, a comparison of wastewater applied at Pauls Valley, Oklahoma (3) and Easley, South Carolina (5) overland flow sites demonstrates that the ratio of ammonium- to organic-nitrogen in the raw wastewater is very different. Also, the reduction of ammonium-nitrogen and total phosphorus as a result of preapplication secondary treatment in these two overland flow sites varied significantly. Several small-scale greenhouse studies, pilot experiments, and full-scale operations have been carried out to renovate raw or pretreated wastewater using overland flow treatment systems. The efficiency of nitrogen and phosphorus removal by overland flow treatment as a function of season, slope of treatment area, loading rates, and frequency of wastewater application has also been investigated in several of these studies. Results of these studies are reviewed here.

Seasonal Effects

The use of overland flow treatment systems has generally been limited to Southern States with year-round warm climates. Several studies were carried out in recent years to investigate the year-round performance of overland flow in the cold climates where temperatures fall below zero in the winter months (3,7,8,9). Data summarized in Table 2 suggest that mass removal of total nitrogen by the overland flow system was substantially reduced in winter months. This reduction in nitrogen removal due to cold weather was evident when raw wastewater (9), primary wastewater (8), or secondary

Table 2. Efficiency of nitrogen removal in overland flow treatment systems.

Overland Flow Site	N form	% N removal					
		Summer			Winter		
		Raw Wastewater	Primary Wastewater	Secondary Wastewater	Raw Wastewater	Primary Wastewater	Secondary Wastewater
Utica, Mississippi (7)[a]	total	—	—	91	—	—	74
Hanover, New Hampshire (8)	total	—	94	87	—	25	32
Pauls Valley, Oklahoma (3)	NH_4^+-N Organic-N	59 41-46	— —	72-74 32-34	42-48 45-50	— —	19-20 38-43
Ada, Oklahoma (9)	total	90	—	—	<75-85	—	—
Easley, South Carolina (5)	Organic-N NH_4^+-N NO_3^--N	70 79 79 annual	—	16 58 52 annual			
Melbourne, Australia (2)	total	—	—	—	—	40	—
Paris, Texas (10)	total	92 (annual)	—	—	—	—	—

[a] Numbers in parentheses refer to the references listed at the end of the paper.

wastewater/lagoon effluent (7,8) was applied at overland flow sites. Lee and Peters (7) reported that cooler winter temperatures suppressed both grass growth and nitrogen uptake as well as microbial activity, thus reducing denitrification losses. Based on their data, these authors suggested that reducing wastewater loading rates and increasing application time may enhance nitrogen removal. Jenkins and coworkers (8) monitored ammonium-nitrogen concentrations in runoff waters from overland flow treatments receiving both primary and secondary wastewater and correlated them with soil temperature. The authors reported a highly significant inverse relationship fitting a second-order polynomial. Their data, reproduced in Figure 1, indicate that ammonium-nitrogen treatment began to decrease at 14°C and ceased when the soil temperature dropped below 4°C. Based on these results, the authors suggested that wastewater applications should be discontinued when the soil temperature at the overland site decreased to 4°C. Based on the soil temperatures at the overland flow site in Hanover, New Hampshire, the authors also suggested that approximately 135 days of wastewater storage would be used in winter months before overland flow treatment could be started.

The efficiency of phosphorus removal reported at the Utica, Mississippi, site (7) and Hanover, New Hampshire, site (8) was much lower in winter months as compared to summer months (Table 3). However, the reduction in phosphorus removal due to lower temperatures in winter months at the Ada overland flow site was comparatively small. No meaningful reductions in phosphorus concentrations at the Pauls Valley overland flow treatment system were observed in summer or winter months (Table 3).

Effect of Wastewater Pretreatment

Jenkins and associates (8) reported that nitrogen removal was greater from primary wastewater than the secondary wastewater. Higher total nitrogen concentrations in the runoff from the secondary wastewater were attributed to a higher applied nitrate-nitrogen concentration. Nitrate-nitrogen is not effectively immobilized during overland flow and remains in the mobile dissolved form. The authors suggested that secondary treatment of wastewater prior to application could decrease the nitrogen removal efficiency of overland flow systems. Similar results were reported by Thomas (4), who compared the effects of three levels of wastewater pretreatment on overland flow performance. Overland flow treatment of raw wastewater was the most effective for nitrogen removal followed by primary treatment, while secondary treatment was the least effective in nitrogen removal. Based on the results of this study and earlier results (11), Thomas hypothesized that the higher oxygen demand in the raw wastewater depleted available oxygen and sustained a low oxygen environment which promoted denitrification following nitrification in aerobic areas. The secondary level of preapplication treatment reduced the oxygen demand in the wastewater to the point where denitrification was limited by higher oxygen concentrations. This resulted in higher nitrate-nitrogen concentration in the runoff water. A higher efficiency of nitrogen removal from raw wastewater compared to lagoon effluent in a year-round operation was also reported in the Easley, South Carolina, overland flow site, Table (2). However, Pollock (5) observed that nitrate concentrations in the runoff waters from the raw wastewater plots increased with distance and the rate of increase was greatest over the last half of the plot. Based on the

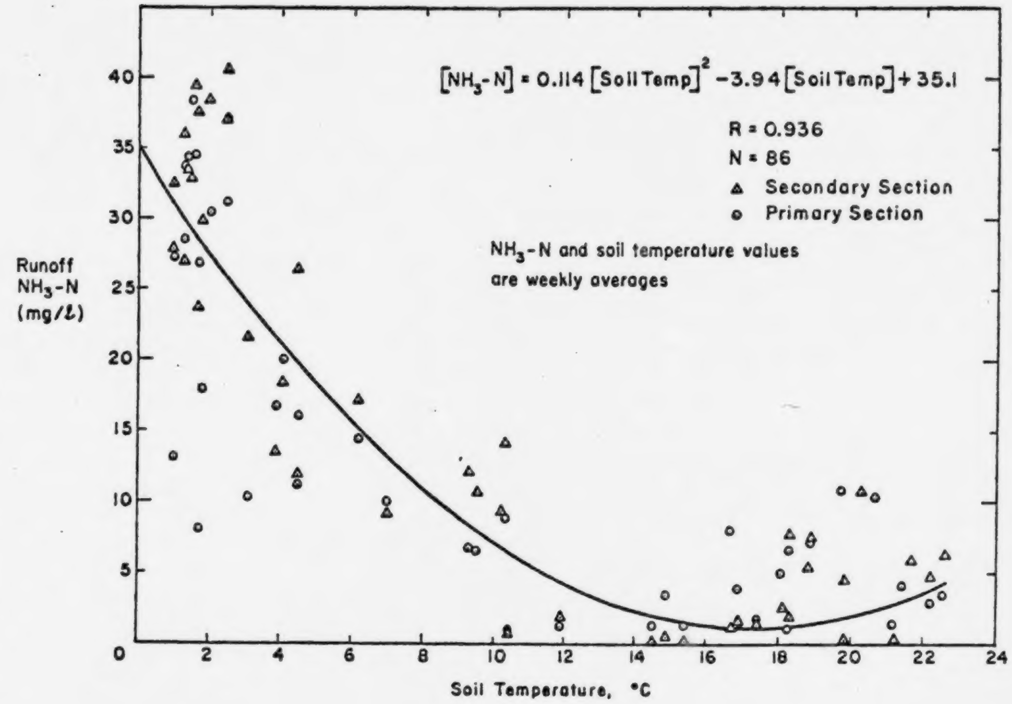

Figure 1. Runoff NH_3-N concentration vs soil temperature for application rate of 5 cm/week (8).

Table 3. Efficiency of phosphorus removal in overland flow treatment systems.

Overland Flow Site	% removal of total P					
	Summer			Winter		
	Raw Wastewater	Primary Wastewater	Secondary Wastewater	Raw Wastewater	Primary Wastewater	Secondary Wastewater
Utica, Mississippi (7)[a]	—	—	60	—	—	38
Hanover, New Hampshire (8)	—	89	80	—	31	30
Pauls Valley, Oklahoma (3)	-5 — -7	—	7-11	8-10	—	10-14
Ada, Oklahoma (9)	60	—	—	50	—	—
Easley, South Carolina (5)	56 (annual)	—	43 (annual)			
Melbourne, Australia (2)	—	—	—	—	15	—
Paris, Texas (10)	62 (annual)	—	—	—	—	—

[a] Numbers in parentheses refer to the references listed at the end of the paper.

concentration profiles of organic-, ammonium-, and nitrate-nitrogen, Pollock concluded that organic- and ammonium-nitrogen were being released to the bulk solution in the first half of the plot length and were subsequently nitrified in the last half of the plot length. The extent of denitrification was limited in the downslope distances because all available carbon was removed in the first half. The author also reported that denitrification of nitrate-nitrogen may also have been inhibited by dissolved oxygen concentrations greater than 0.2 mg/ℓ, a likely occurrence from the large interface available for transfer from the atmosphere. These nitrification-denitrification relationships in the overland flow system are discussed later in the paper.

Data summarized in Table 3 show that phosphorus removal efficiency was greater in raw or primary wastewater as compared to secondary wastewater. Thomas (4) also reported a general decrease of phosphorus removal by overland flow treatment with greater preapplication treatment. However, the behavior of phosphorus at the Pauls Valley overland flow treatment facility (3) was different from most other sites. Phosphorus concentrations in the runoff waters increased significantly or registered a very slight decrease as a result of overland flow treatment.

Effect of Slope of Treatment Area

The U.S. EPA recommends a slope of 2 to 8% for normal overland flow operations (1). The cost and impact of earthwork required for slope modifications are considered to be major constraints in the selection of overland flow sites. A comprehensive overland flow pilot project was established at Utica, Mississippi, which investigated the effects of several environmental variables including slope on overland flow performance (12). The results of this study suggest that no differences in nitrogen and phosphorus reduction were observed in overland flow plots established at 2, 4, and 8% slopes. Hall and associates (3) also concluded, from the results of Pauls Valley overland flow treatment system, that variation of slope from 2 to 3% had no significant effect on nutrient reductions. Based on the review of overland flow studies, Lee and associates (13) suggested that application sites should have slopes of 2 to 8%, preferably between 2 to 4%.

Effect of Loading Rates

In an interim criteria for overland flow treatment performance, Lee and associates (13) proposed that the application rates of wastewater should not exceed 0.5 in./acre/day except in summer months when evapotranspiration is very high. They also suggested a 6- to 18-hour application period four to five days a week in order to maintain a balance between aerobic and anaerobic soil conditions. The effects of loading rates and application periods on overland flow performance have also been studied in pilot field experiments. Thomas (4) concluded that increasing the loading resulted in an increase in the concentrations of both nitrogen and phosphorus in runoff waters from the raw, primary, and secondary wastewater treatment plots. The best performance for both nitrogen and phosphorus removal was for the lowest loading (5.2 meter/year) of raw wastewater, while the poorest removal was for the highest loading (20.8 meter/year) of secondary effluent. Working with an overland flow treatment of lagoon effluent, Peters and Lee (12) reported that maximum reductions of both nitrogen and phosphorus could be achieved at application rates of 2.54 cm in 18 hours for the warmer months of the year, and at 1.27 cm in 18 hours for the cooler winter months. These results indicate that nutrient removal efficiency of overland flow systems was significantly affected by wastewater loading rates in cooler winter months because of reduced plant growth and microbial activity.

NITROGEN REMOVAL PROCESSES

The major physical, chemical, and biological processes involved in the removal of nitrogen during overland flow treatment of municipal wastewater include ammonia volatilization, adsorption of ammonium-nitrogen by the soil exchange complex, immobilization of ammonium- and nitrate-nitrogen by soil microorganisms and organic matter, mineralization of organic-nitrogen, nitrification-denitrification reactions, and plant uptake. Ammonia volatilization, denitrification, and plant uptake are directly involved in the removal of wastewater nitrogen, while other processes indirectly influence the reduction of nitrogen in the runoff and subflow through various nitrogen transformations. A schematic diagram of the various nitrogen removal processes is presented in Figure 2. Some of these processes are discussed below.

Ammonia Volatilization

Volatilization of wastewater ammonium-nitrogen as free ammonia (NH_3) from the soil surface is an important chemical reaction resulting in the loss of applied ammonium-nitrogen to the atmosphere (14). Raw, primary, and secondary wastewater contain a substantial portion of total nitrogen in the ammonium form which is subject to volatilization losses (Table 1). The magnitude of ammonia volatilization is largely controlled by the pH of the soil and applied wastewater, loading rates, clay content of the soil, cation exchange capacity, plant canopy, the ammonium-nitrogen concentration gradient between the soil-water surface and the atmosphere, and temperature (1,15,16, 17,18). Khalid and associates (19) reported that ammonia volatilization losses of applied ammonium-nitrogen in small-scale overland flow experiments and growth chamber studies accounted for about 5% of the total nitrogen added. The pH of soils used in these studies ranged from 6.4 to 7.6 and would therefore explain the relatively small losses through ammonia volatilization. Published literature suggests that ammonia volatilization losses would be appreciable under more alkaline soil conditions (16). The loss of wastewater nitrogen during winter months in the Pauls Valley, Oklahoma, overland flow treatment facilities was primarily attributed to ammonia volatilization (3). The low temperatures during winter months inhibited nitrification-denitrification reactions and reduced plant growth; the only nitrogen removal mechanism occurring was ammonia volatilization. The ammonia volatilization losses were estimated at about 50% for the raw wastewater and less than 40% for the secondary wastewater treatment system. However, there are no data available on the field measurements of ammonia volatilization during overland flow treatment of wastewater.

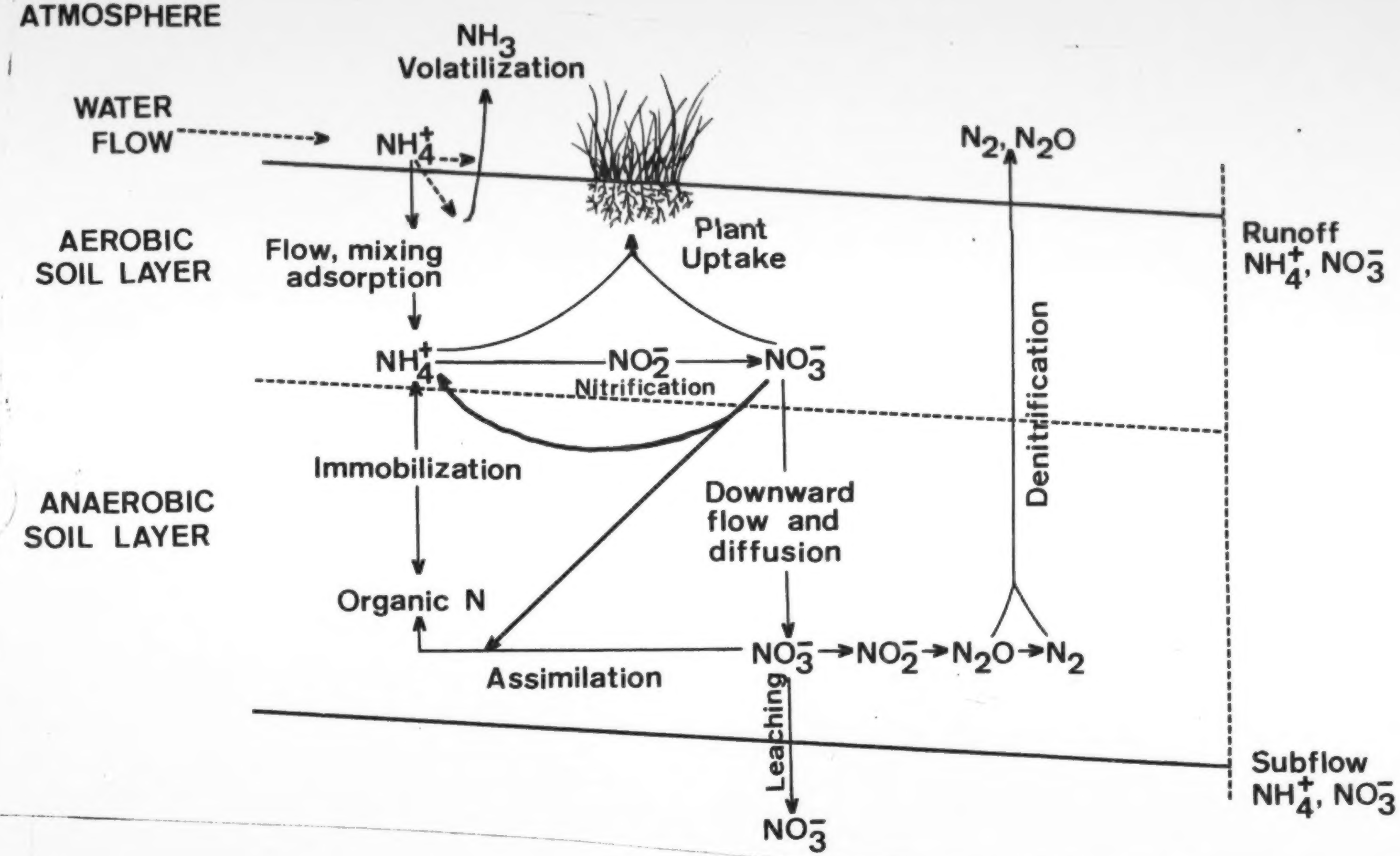

Figure 2. A schematic diagram of various nitrogen removal processes occurring in an overland flow treatment of wastewater (19).

Nitrification-Denitrification Reactions

Of the biochemical reactions, nitrification and denitrification are very important in the removal of wastewater nitrogen. Nitrification is important because it converts ammonium-nitrogen adsorbed on the soil exchange complex and not easily diffusable, to nitrate-nitrogen that moves readily to the lower anaerobic soil layers with the percolating water (Figure 2). Denitrification is important because it is the principal biochemical process by which nitrate-nitrogen is lost from the soil system through conversion to nitrous oxide and dinitrogen gases (Figure 2). The overland flow treatment of wastewater produces conditions favorable for the simultaneous occurrence of both nitrification and denitrification reactions. For example, the slow diffusion of oxygen through the water results in the development of a thin oxidized layer, which is characterized by a high redox potential and a high content of the oxidized forms of nitrogen such as nitrate and nitrite. Below this oxidized layer, the absence of oxygen results in a reduced zone characterized by low redox potential, the presence of reduced products of nitrogen and the products of anaerobic decomposition of organic matter. Oxidized conditions favor conversion of applied ammonium to nitrate (nitrification), which may leach to the lower anaerobic layer or be taken up by plants. In the absence of oxygen, gaseous nitrogen losses of nitrate (denitrification) and nitrogen mineralization releasing free ammonium are favored. The transformation of gaseous- and ammonium-nitrogen to organic amino acids and proteins (nitrogen fixation) is also accelerated by reduced conditions which may decrease levels of soluble nitrogen and are thus of great benefit in the tertiary treatment of wastewater by land application.

Measurements of redox potentials in the surface and subsurface soils during overland flow applications in various studies indicate that redox potential values oscillated between oxidized and reduced conditions, suggesting the existence of soil environment favorable for nitrification-denitrification reactions (19,20,21).

The environmental factors that may limit biological oxidation of ammonium-nitrogen to nitrate-nitrogen include the number and type of nitrifying microorganisms present, soil pH, temperature, and oxygen supply (1). In small-scale experiments, the establishment of an overland flow treatment system in soils with pH values below 6.0 was shown to result in an incomplete nitrification of ammonium-nitrogen and to limit the proportion of nitrate-nitrogen available for denitrification reactions (19). The effect of low winter temperatures on the reduction of nitrification has also been reported in field overland flow studies (3). However, oxygen supply may not be a limiting factor for nitrification reactions in overland flow systems due to continuous aeration of surface water as it moves over the land via sheet flow (1).

Denitrification, the microbial conversion of nitrate-nitrogen to nitric oxide (NO), nitrous oxide (N_2O), or nitrogen gas (N_2) is a major process by which ammonium-nitrogen may be lost to the atmosphere. The overall nitrification-denitrification reaction proposed by Patrick and Reddy (22) may be written as follows:

$$24\ NH_4^+ + 48\ O_2 = 24\ NO_3^- + 24\ H_2O + 48\ H^+ \qquad \text{(Equation 1)}$$

$$24\ NO_3^- + 5\ C_6H_{12}O_6 + 24\ H^+ = 12\ N_2 + 30\ CO_2 + 42\ H_2O \qquad \text{(Equation 2)}$$

$$24\ NH_4^+ + 5\ C_6H_{12}O_6 + 48\ O_2 = 12\ N_2 + 30\ CO_2 + 66\ H_2O + 24\ H^+ \qquad \text{(Equation 3)}$$

The nitrate-nitrogen formed during these processes, therefore, is an intermediate product in the overall pathway between ammonium-nitrogen and nitrogen gas. The environmental factors important in the denitrification of nitrate-nitrogen include easily available energy sources, moderately reduced soil conditions, favorable soil pH and temperature, and an adequate population of denitrifying microorganisms (1,23,24,25,26).

The commonly accepted pathway of microbial denitrification is:

$$NO_3^- \longrightarrow NO_2^- \longrightarrow NO \longrightarrow N_2O \longrightarrow N_2 \qquad \text{(Equation 4)}$$

Nitrous oxide is seldom a major product of denitrification (27). Nitrous oxide is an intermediate in denitrification and may be evolved from the soil before it is further reduced to nitrogen gas, particularly when it is produced near the surface (1). High nitrous oxide releases relative to nitrogen gas were reported to occur only under conditions unfavorable for high rates of denitrification (28). Although the role of denitrification in the conversion of nitrate-nitrogen to gaseous end products has been extensively discussed, little information is available on the relative magnitude of losses of applied nitrogen in soil-grass systems as gaseous nitrogen.

Catchpoole (29) reported that gaseous loss of applied nitrogen-15 from a Rhode grass-pasture field microplot reached as high as 27% when the soil was waterlogged. Gaseous losses of applied nitrogen were reported to be small or absent at a soil moisture content below field capacity. Stefanson (30) measured the denitrification losses of applied nitrate-nitrogen in reconstituted soil profiles in sealed growth chambers. His results showed that plant growth had a stimulating effect on the reduction of nitrate-nitrogen to gaseous nitrogen (nitrogen gas and nitrous oxide) in a cropped soil. In a pasture soil, on the contrary, plant growth generally had little effect on the denitrification rate. This difference in nitrate reduction was attributed to the organic carbon level in the soil under study. In an earlier study on the losses of volatile nitrogen from agricultural soils in sealed growth chambers, Stefanson (31) reported a significantly higher loss of applied nitrate-nitrogen compared to ammonium-nitrogen. The major component of these losses was nitrogen gas, with lesser quantities of nitrous oxide. However, both gases were shown to be produced by biological denitrification of soil nitrate. Significant gaseous nitrogen loss of applied nitrogen through nitrification-denitrification reactions in land treatment of wastewater has not been reported, although it has been hypothesized to occur in overland flow systems and is known to be significant in rice paddies and marsh areas (21,32,33).

Khalid and coworkers (19) conducted a series of small-scale overland flow experiments to determine the mechanisms and magnitude of denitrification losses of applied ammonium-nitrogen. The results of these controlled greenhouse studies indicate that 2.8 to 35.4% of labelled ammonium-nitrogen was lost from the soil-plant system through denitrification reactions. The mass spectrometric measurements of evolved nitrogen-15 gas in a sealed soil-plant overland flow system during the 90-day experimental period are presented in Figure 3. The data plotted in Figure 3 indicate that nitrogen gas production steadily increased with time, although not at the same rate, and a maximum concentration of over 1200 mg $^{15}N_2/m^3$ was detected at the end of the 90-day overflow treatments. The proportionately greater nitrogen gas production in the last 20 days was attributed to more reduced soil conditions in the subsurface soil favorable to the biological denitrification of nitrate-nitrogen present in the soil. No nitrous oxide gas was detected in the closed atmosphere. The absence of nitrous oxide in the system was attributed to the high soil pH of 6.6 to 7.6 which favors nitrogen gas formation. Studies on denitrification products show that acid conditions are more favorable for the formation of nitrous oxide and nitric oxide than neutral and alkaline conditions which enhance nitrogen gas (34,35). Although the recovery of nitrogen gas in the sealed overland flow system was qualitative and incomplete, it demonstrates the occurrence of denitrification reactions in the overland flow treatment system (19).

In sealed growth chamber studies where alternately oxidized and reduced soil conditions were created with controlled soil moisture, denitrification loss of applied labelled ammonium-nitrogen was as high as 59% (19). The results of overland flow and growth chamber experiments show that no significant accumulation of nitrate-nitrogen occurred in the soil mass, which indicated that the denitrification process was not a limiting factor in the gaseous loss of applied nitrogen. Based on these studies, the authors suggested that the gaseous loss of applied nitrogen could be maximized during land application of wastewater if conditions favorable for simultaneous nitrification-denitrification reactions were attained through careful manipulation of the soil-plant system. Chen and Patrick (36) conducted a small-scale overland flow experiment with simulated wastewater containing 25 μg/ml labelled ammonium-nitrogen and constructed a mass balance of applied nitrogen-15 in different components of the overland flow system at the end of 32-day experiment. The data indicated that 61.3% of applied nitrogen could not be accounted for and may be attributed to gaseous nitrogen losses. The ammonia volatilization loss was estimated to be only about 2%, which means that over 59% of applied ammonium-nitrogen was lost through denitrification reactions. No measurements of nitrous oxide or nitrogen gas were made in this study. Using a similar experimental set-up, Smith and associates (37), measured nitrous oxide evolution from simulated overland flow models receiving daily applications of wastewater containing 10 to 47 μg ammonium-nitrogen/cm^3. The results indicated that increasing ammonium-nitrogen concentrations in the wastewater and liming the soil increased nitrous oxide production. However, the maximum recovery of nitrous oxide was less than 1.2% of applied

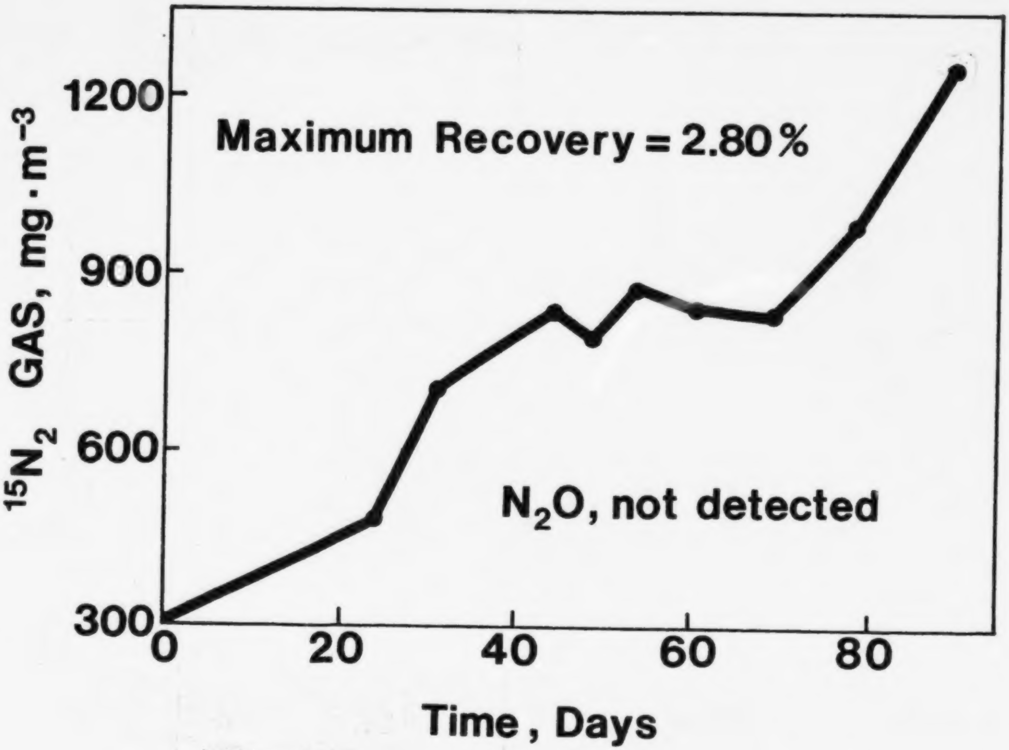

Figure 3. Gaseous nitrogen-15 production as a function of time in a sealed overland flow Olivier soil-Bermuda grass system (19).

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ammonium-nitrogen, implicating nitrogen gas as the major denitrification end product in the overland flow treatment model. No measurements of nitrogen gas were made in this study.

Plant Uptake of Nitrogen

Plant uptake of nitrogen is a major factor in the renovation of municipal wastewater by overland flow treatment systems (21,38). Several grasses, such as reed canary, bermuda, fescue, and rye, have been used alone or in mixtures in overland flow systems (39). Grass cover has been reported to be more effective than other types of crops due to the tolerance of high wastewater loading rates and high nutrient uptake of grasses (1,39). Palazzo and co-workers (40) studied the performance of several grass species in an overland flow system and reported that orchard grass and tall fescue were the best suited, followed by Kentucky bluegrass and quackgrass. They suggested that the spread of undesirable plants should be avoided to maintain a high rate of plant uptake. The results of this study indicate that about 62% of applied wastewater nitrogen was taken up by the growing plants. Removal of 42% of the nitrogen applied in cannery wastewater by reed canary grass has been reported for the Campbell Soup Company, Paris, Texas overland flow treatment system (41). Carlson et al. (21) reported that 31% of the nitrogen applied in a secondarily-treated municipal effluent was removed by the grass sod in an overland flow test model maintained at a 2% slope. In a similar study of overland flow treatment of wastewater applied to a clay soil-reed canary grass system, 75.9% of the applied nitrogen was shown to be incorporated into grass tissue (20). Khalid and associates (19) conducted several small-scale overland flow and growth chamber studies to determine the relative contribution of different nitrogen removal processes in the renovation of wastewater. The results of these studies indicate that 23 to 62% of applied nitrogen was taken up by the growing plants (rye grass, bermuda grass, or reed canary). Plant uptake accounted for the greatest removal of wastewater nitrogen compared to other chemical and biological processes. The significantly large fraction of nitrogen removed by the plants in the studies cited above suggests that vegetative growth may be an efficient component in the overland flow treatment of wastewater.

Some of the biochemical processes that have an indirect influence in reducing the levels of nitrogen in runoff and subflow include immobilization of ammonium-nitrogen by the microorganisms and soil organic matter and conversion of nitrate-nitrogen to organic nitrogen. Conversion of both ammonium- and nitrate-nitrogen to organic-nitrogen with subsequent mineralization of organic nitrogen to the ammonium form further facilitate removal of nitrogen by various processes. The role of these processes in the overall distribution of nitrogen in land application of wastewater and the eventual reduction of groundwater and stream contamination are illustrated in Figure 2. A more detailed discussion of these immobilization-mobilization processes is given elsewhere (1,42).

PHOSPHORUS REMOVAL PROCESSES

Phosphorus present in wastewater is generally removed during overland flow treatments by (a) accumulation in the solid phase of the soil as organic compounds, adsorbed ions, or precipitated inorganic compounds (phosphorus immobilization); and (b) plant uptake. The relative contributions and mechanics of these two processes in phosphorus removal are discussed here.

Phosphorus Immobilization

The main soil constituents that react with phosphorus at concentrations usually found in wastewaters are iron and aluminum present as soluble ions, oxides, hydroxides, and silicates; and calcium present as a soluble ion and as carbonate. Soluble inorganic phosphorus present in the applied wastewater is immobilized in the soil by chemical adsorption and precipitation reactions. In the adsorption process, phosphorus reacts with iron, aluminum or calcium ions exposed on solid surfaces. Reactive iron and aluminum surfaces can occur at the broken edges of crystalline clay minerals, as surface coatings of oxides or hydroxides on crystalline clays, and at the surfaces of particles of oxides and hydroxides and of amorphous silicates. Positively charged hydroxide polymers of aluminum and exchangeable aluminum ions in acid soils can also adsorb phosphorus. Reactive calcium surfaces are mainly found on solid calcium carbonate and calcium-magnesium carbonates. Precipitation reactions occur with soluble iron, aluminum, and calcium, resulting in the formation of relatively insoluble iron, aluminum, and calcium phosphates. The disappearance of soluble phosphorus is generally described by a two-step process. The first reaction, which is very fast and reversible, is considered to be adsorption. The second process is a long-term, relatively slow precipitation of phosphorus compounds of limited solubilities, and the regeneration of adsorptive surfaces. Both adsorption and precipitation reactions are complex and overlapping, and uncertainty as to whether phosphorus is being adsorbed or precipitated led researchers to use the term "sorption", which covers both processes and means only that the phosphorus has been removed from solution (1,43).

Soil phosphorus sorption capacity is possibly the most important soil criterion for the selection of sites for the application of wastewater. Various forms of Langmuir and Freundlich equations have been extensively used to determine the phosphorus sorption capacities of soils (43,44,45,46). Although these two models have been successfully used to give relative measures of the original initial sorption capacities, neither the Freundlich nor the Langmuir models are reported to provide information concerning the mechanism by which phosphorus is retained in soil over an extended period (47,48). The suitability of various models to describe phosphorus behavior in soils has been extensively discussed in two recent reviews (49,50).

The phosphorus sorption capacity of soils is governed by the amount and type of clay minerals present (51,52), soil pH (51,53), the levels of extractable iron and aluminum oxides present (54,55,56,57), and oxidation-reduction conditions (19,57). Other variables that influence the sorption of soluble phosphorus by a soil include concentration of phosphorus in solution, temperature, time, the total amount of phosphorus added, and the concentration of soluble aluminum, iron, or calcium ions (1). The factors that significantly affect phosphorus sorption/desorption reactions in land treatment systems include aluminum, iron, and calcium chemistry, pH, and oxidation-reductions conditions (19,58,59).

The phase diagrams developed by Lindsay and Moreno (60) and Enfield and Bledsoe (43) for a number of phosphorus compounds suggest that aluminum and iron phosphates predominate in soils whose pH is lower than 6.0. In neutral and alkaline soils, several calcium phosphate compounds of varying solubilities control phosphorus solubility. A significant difference between the iron and aluminum phosphate system and the calcium phosphate system, relative to the application of wastewaters to soils, is that these waters may contain only traces of iron and aluminum, but they usually contain substantial amounts of calcium. The reactions with iron and aluminum are thus limited to the supplies of these elements in the soil, whereas the water may supply its own calcium, setting up a system that can precipitate calcium phosphates indefinitely. In calcareous soils, calcium carbonate can also be a highly significant source of calcium for the precipitation of phosphorus over an extended period of time (1).

Holford and Patrick (61) studied the effects of soil reduction and pH changes on phosphorus sorption and mobility in an acid soil high in extractable iron. Their results indicate that soil reduction at pH 5.0 caused a decrease in phosphorus sorption at solution phosphorus concentrations below 20 ppm because of the reduction and dissolution of ferric hydrous oxides. At higher phosphorus concentrations, sorption was increased by ferrous phosphate precipitation due to very high concentrations of soluble iron. A very large increase in phosphorus sorption due to soil reduction at pH 6.5 was attributed to increased adsorption of phosphorus on freshly precipitated amorphous ferrous hydroxide. Phosphate sorption at pH 8.0 was reported to result from calcium phosphate precipitation. The authors reported that soil reduction increased the concentration of soluble phosphorus at all pH levels. The results of this study suggest that changes in redox potential affected iron transformations, while pH governed the dissolution and subsequent reprecipitation of the reduced compounds. A close positive relationship between increased phosphorus sorption and extractable iron in anaerobic flooded soils in an earlier study also suggested that poorly crystalline and amorphous oxides and hydrous oxides of iron played a primary role in phosphorus retention by slightly acidic to near-neutral soils (57).

Khalid and associates (19) conducted a small-scale overland flow experiment to determine the phosphorus-32 removal efficiency of prereduced and limed soil treatments. The effect of these pretreatments on the efficiency of phosphorus-32 removal in the overland flow model is illustrated in Figure 4. The mass balance of phosphorus-32 showed that 78.3, 70.4, and 51.0% of added phosphorus was sorbed by the soil mass in the limed, prereduced, and untreated control treatments, respectively. The presence of excess calcium carbonate (60 meq/100 g soil) in the soil apparently resulted in the precipitation of simulated wastewater phosphorus as calcium phosphate during overland flow treatments. Several calcium compounds of varying solubilities have been reported to be formed with phosphate under alkaline soil conditions. Some of the important calcium phosphate compounds formed after reaction with calcium carbonate that limit orthophosphate solubility in soils are dicalcium phosphate dihydrate [$CaHPO_4.2H_2O$], tricalcium phosphate [$Ca_3(PO_4)_2$], octacalcium phosphate [$Ca_4H(PO_4)_3 \cdot 3H_2O$], and hydroxyapatite [$Ca_5OH(PO_4)_3$]. The negatively increasing solubility product constants (-pKsp) of 6.56, 26.0, 46.91, and 55.60, respectively, for the compounds listed above suggest decreasing

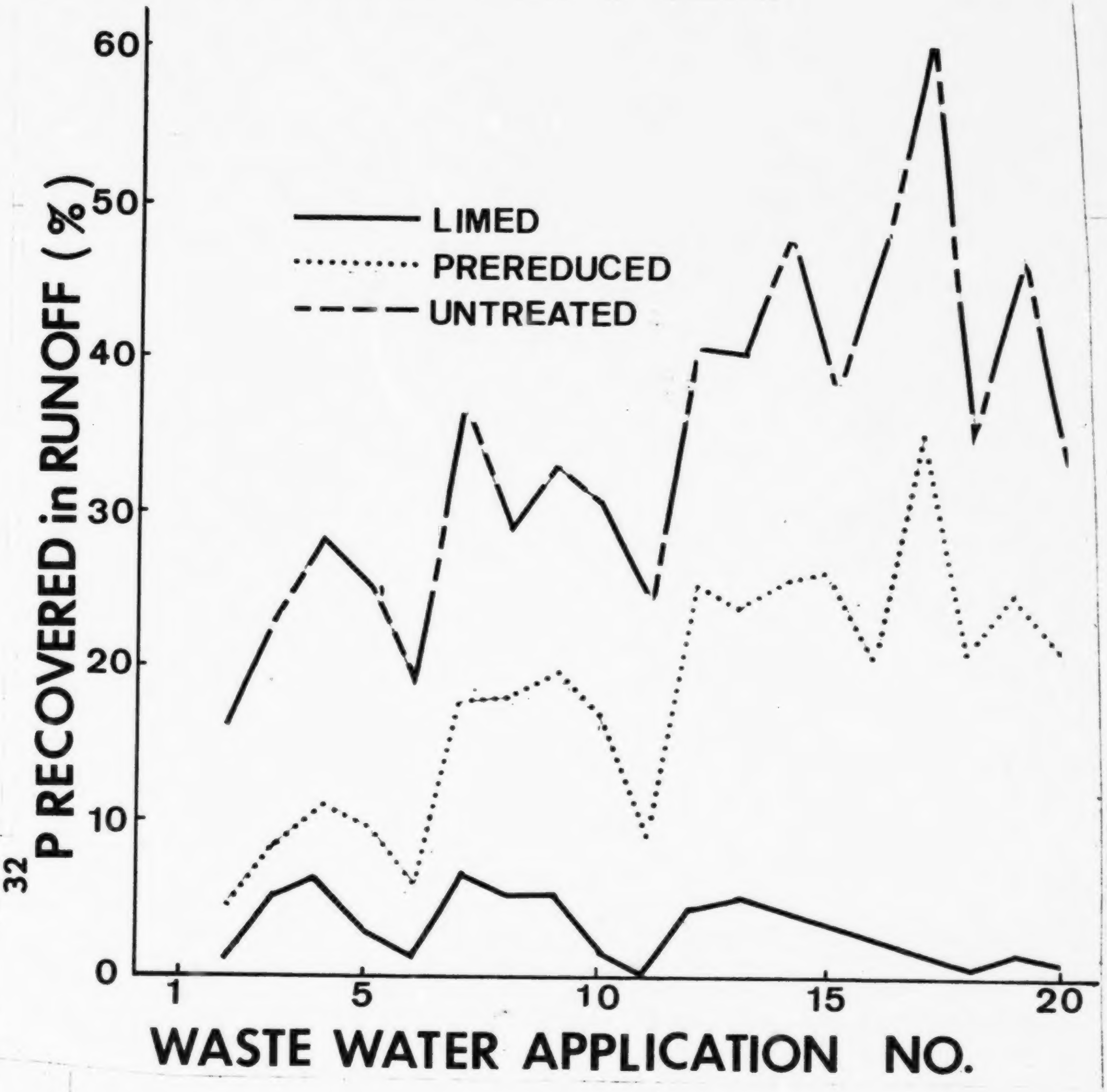

Figure 4. Effect of soil pretreatments on the efficiency of phosphorus-32 removal from simulated wastewater in Crowley soil-rye grass system in an overland treatment model (19).

solubility with increased calcium reaction and hence greater retention of added phosphate (43,62,63,64). The sorption of added phosphorus in the limed treatments during four weeks of overland flow treatment was suggested to be a combined effect of soil adsorption as well as calcium phosphate precipitation during the experimental period (19). Adsorption by hydrous oxides in the limed treatments may not play a significant role due to insignificant dissolution of iron compounds in the pH range of 7.1 to 7.7 attained in this soil treatment. Since no calcium carbonate was added to Crowley soil in the prereduced and untreated soil treatments the sorption of added phosphorus may involve ferric phosphate [$FePO_4$] as well as ferrous phosphate [$Fe_3(PO_4)_2$] precipitation, adsorption by reprecipitated ferrous hydroxide [$Fe(OH)_2$] and sorption on soil exchange sites. The redox potential measurements in these two unlimed treatments fluctuated from -70 mv to over +600 mv suggesting conversion of ferric to ferrous ions. In the prereduced treatment the soil was allowed to equilibrate under waterlogged conditions for 13 weeks prior to the addition of soluble phosphate during overland flow treatment which may have resulted in more iron converted from ferric oxides to ferrous hydrous oxides than in the untreated soil thus increasing phosphorus sorption (57).

The use of aluminum compounds in the removal of wastewater phosphorus in the overland flow treatment model has been successfully demonstrated in field experiments. Thomas and associates (9) conducted a 15-month-long overland flow study on the efficiency of aluminum sulfate in removing raw wastewater phosphorus as aluminum phosphate precipitate and reported that a 1:1 stoichiometric balance of aluminum to phosphorus reduced the raw wastewater phosphorus concentration of 10.4 mg P/ℓ to about 1.5 mg P/ℓ. The use of a 2:1 balance achieved an additional reduction in the runoff phosphorus concentration to about 1.0 mg P/ℓ. The application of aluminum sulfate to lagoon effluent prior to overland flow treatments was also reported to reduce the wastewater phosphorus concentration of 10 mg P/ℓ to 2 mg P/ℓ or less in an overland flow pilot study in Mississippi (7).

No field estimates of the fraction of wastewater phosphorus retained by the soil complex in overland flow treatment systems are available.

Plant Uptake of Phosphorus

Due to lower requirements for phosphorus than nitrogen for normal plant growth, plant removal plays a minor role in the reduction of wastewater phosphorus. Published literature indicates that the amounts of phosphorus removed by the harvested portions of various agronomic and pasture crops vary from 11 to 95 kg/ha/yr and that of nitrogen from 56 to 450 kg/ha/yr (1). A few studies have reported phosphorus removal efficiency of growing plants in the overland flow treatment models. C. W. Thornthwaite and associates (65) indicated that 17% of phosphorus applied to the Campbell Soup Company overland flow treatment site was taken up by reed canary grass. Martel et al. (66) reported that a mixture of tall fescue, orchard grass, reed canary grass, and rye grass removed 21 and 23% of phosphorus from the secondary and primary wastewater, respectively, applied to an overland flow treatment model established in Hanover, New Hampshire. Palazzo and coworkers (40) reported that 54% of domestic wastewater phosphorus was removed during a six-month study. In a small-scale overland flow study, Khalid and associates (19) reported that 11.3 to 18.4% of phosphorus-32 applied in the simulated wastewater was taken up by rye grass plants. However, it is postulated that a major part of the phosphorus required by the cover crop during a growing season is met by residual soil phosphorus, and the cover crop plays only a minor role in the removal of wastewater phosphorus compared to soil immobilization processes (3,38).

In a manual for land treatment of municipal wastewater published by the U.S. EPA (1), it is suggested that the use of forage crops for overland systems, frequent harvesting of growing grasses, and double cropping can significantly increase phosphorus removal by the cover crops.

SUMMARY

A review of recently published literature on the efficiency of nitrogen and phosphorus removal during overland flow treatment of municipal wastewater is presented in this paper. The results of various studies suggest overland flow to be an effective treatment system for removal of nitrogen from municipal wastewater while phosphorus removal efficiency varies over a wide range. The removal of both nitrogen and phosphorus was substantially reduced in winter months and this reduction was evident when raw, primary, or secondary wastewater was applied at overland flow sites. The results of pilot overland flow research studies suggest that reducing wastewater loading rates and increasing application time in the mild winter climates may enhance nutrient removal. In areas where winter temperatures stay below freezing for extended periods, wastewater may be stored until overland flow treatment could be restarted.

Preapplication treatment (primary or secondary) of raw wastewater resulted in reduced efficiency of overland flow system in removing nitrogen and phosphorus. This reduction in nitrogen removal due to pretreatment was attributed to lower oxygen demand which limited denitrification losses of nitrate-nitrogen. The nitrate-nitrogen concentrations in runoff waters were directly related to the levels of wastewater pretreatment. Variations in the slope of overland flow sites from 2 to 8% did not significantly affect nutrient removal efficiencies.

The contribution of various nitrogen and phosphorus removal mechanisms operating in the overland flow treatment of wastewater was also reviewed in this paper. Nitrogen removal was attributed to gaseous nitrogen losses through denitrification reactions, plant uptake by the established vegetation, and under alkaline conditions, to ammonia volatilization losses. The results of various laboratory and field studies suggest that the gaseous loss of applied nitrogen can be maximized during overland flow application of wastewater containing ammonium-nitrogen if conditions favorable for simultaneous nitrification-denitrification reactions are attained. Some of the important factors that control these reactions are redox potential, pH, energy source, and microbial populations. The contribution of various mechanisms involved in the overall nitrogen removal was discussed in the paper.

Phosphorus removal from wastewater during overland treatment is attained through sorption by the soil complex and uptake by the growing plants. Extensive research has been conducted on the mechanisms and kinetics of phosphorus sorption,which include adsorption and precipitation reactions. The capacity of a soil to sorb phosphorus depends primarily on the concentration of iron, aluminum, and calcium compounds in the soil which react with wastewater phosphorus. A number of physicochemical parameters including soil pH, redox potential, and time of reaction, significantly affect the equilibrium between solution- and solid-phase phosphorus and hence determine the magnitude of phosphorus removed from wastewater. Although chemical precipitation is known to be effective in phosphorus removal, very few studies have been conducted to demonstrate the usefulness of aluminum compounds or lime applications in enhancing phosphorus removal. More research also need to be conducted on the selection of plant species that have greater affinity for nutrient removal and that can be harvested often to maximize both nitrogen and phosphorus removal.

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Question (by Mr. Rex Hunt, Texas Department of Health, Arlington, TX): Did you say that wetting and drying of the soils produce phosphorus compounds that are more strongly fixed in the soil?

Response (by Dr. Patrick): Yes, it is related to the effect of the wetting, or the exclusion of oxygen, on the iron compounds. When a soil is wet enough for the oxygen to be depleted from the soil, insoluble ferric iron compounds are converted to the more soluble ferrous form. The soluble ferrous irons are very reactive with phosphate, and phosphate will be sorbed on the surfaces of soil particles. But these are not very insoluble, so phosphorus can be solublized very easily from this ferrous phosphate. If oxygen reenters, then the ferrous phosphate is converted to ferric phosphate, which is much more insoluble than the ferrous phosphate. Therefore phosphorus is precipitated by converting the relatively soluble ferrous phosphate to highly insoluble ferric phosphate.

Question (by Mr. Ken Barton): What effect would the thickness or depth of the saturated soil layer, or the anaerobic layer, have on the clay layer?

Response (by Dr. Patrick): It doesn't seem to be a very critical factor as long as you have an aerobic zone where the ammonium can be oxidized to nitrate. Apparently, it doesn't take a big zone for that, and you can have an anaerobic or oxygen-free zone of almost any thickness.

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Effects of Suspended Solids on Overland Flow Design and Operation

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INTRODUCTION

Land treatment systems are typically designed based on a land limiting constituent analysis. 5-day biochemical oxygen demand (BOD_5) loadings, nutrient loadings, and hydraulic loadings are all considered and used to establish design requirements for land treatment of municipal wastewaters. A review of the literature (e.g. Ref. 1) shows little consideration given to suspended solids loadings during development of design criteria. Sometimes, suspended solids loadings equal to those used for BOD_5 are used for design. Other designers increase hydraulic loadings if greater pretreatment is provided, especially settling for suspended solids reduction. Finally, many designs more or less ignore suspended solids considerations during designs. This approach is probably justified because overland flow treatment of weak wastewaters, typical of municipal wastewaters, generally has been effective in BOD_5 and suspended solids reduction, and hydraulic loading considerations dominate design requirements.

During operation of overland flow systems, poor suspended solids reductions have resulted. Typically, periods of high effluent suspended solids have been of short duration and have resulted in effluent suspended solids discharges substantially greater than ordinarily observed.

To improve both the design process and the operating procedures, it is important to understand better the removal mechanisms and the nature and sources of the effluent suspended solids. This paper summarizes observations of the effect of suspended solids on operation of the overland flow system at the Culver duck processing plant (2,3), relates these to observations reported in the literature, and discusses removal mechanisms which should both improve design and operating approaches dealing with suspended solids reductions.

OVERLAND FLOW PRETREATMENT

Pretreatment of municipal wastewaters for overland flow treatment can range from preliminary treatment for grease, oil, grit, and large particle removal, to primary treatment for suspended solids reduction, or to secondary treatment for removal of the finely divided and soluble organics. Suspended solids loadings resulting from each of these pretreatment processes are substantially different, therefore proper design of the overland flow system can be accomplished only after pretreatment requirements are clearly defined. Excessive pretreatment is costly, may result in no improvement of overland flow treatment, and may even cause a deterioration in effluent quality or otherwise hinder the operation of the overland flow process.

The Culver duck processing plant wastewater was a weak processing plant effluent and possessed BOD_5, suspended solids, and nutrient concentrations very nearly the same as those of a municipal wastewater. Pretreatment included a fine screen and a gravity grease separator where both floatables and grit were removed. During some monitoring periods, the pretreated wastewater was applied directly to the plot. Effluent suspended solids concentrations were usually between 10 and 20 mg/ℓ, occasionally lower, and were seldom in excess of 30 mg/ℓ.

Essentially no pretreatment was provided during several periods of operation due to inadequate operation of the pretreatment facilities. The large solids entering the overland flow system resulted in serious problems as they accumulated and clogged pumps, pipes, and orifices. Those solids, mainly consisting of feathers and grease, accumulated along the top of the overland flow site and choked the grass and clogged the soil so that a wet anoxic soil condition prevailed.

A third type of pretreatment was also used at the Culver site. The processing plant effluent was passed through a lagoon providing about 10 days to 20 days detention prior to overland flow treatment. No improvement in the overland flow effluent quality, including suspended solids, was observed as a result of the secondary-type influent. In fact, overland flow effluent quality greatly deteriorated during periods when high algae concentrations existed in the lagoon. Overland flow effluent suspended solids were always above 30 mg/ℓ, often two or three times higher, and occasionally approached the influent suspended solids concentration as a result of the influent algae.

EFFLUENT SUSPENDED SOLIDS

Effluent suspended solids originate from many sources. Influent suspended solids which pass through the system as a result of incomplete treatment is one source. Designers and operators must understand removal mechanisms, and must improve treatment efficiencies or modify pretreatment systems to provide for more nearly complete removal of these solids. Another source of effluent solids are those which originate or were generated on the grass-covered plot. These suspended solids may include dislodged soil particles, grass fragments, algae grown on the plot, and bacterial cells and cell fragments. Elimination of these effluent suspended solids may also be important and will likely require different solutions.

At the Culver site, the overland flow plots were constructed on a highly permeable sandy loam soil. Overland flow treatment was made possible by construction of a bentonite clay seal located 15 cm below the grass-covered topsoil layer. Soil erosion, even during periods of relatively intense rainfalls and when the grass cover was poorly established, was not a problem at Culver and contributed little to effluent solids. This was attributed to the heavier sandy soil particles. Most other overland sites have been constructed on clay soils which are less permeable, but more susceptible to erosion, especially during peak rainfall periods or when grass cover is not completely established. In addition, the more granular sandy soil probably provided a better trap of settled suspended solids. Others (4) have reported significant suspended solids increases during rainfalls.

During periods of highest effluent quality, suspended solids concentrations were usually observed to be about 10 mg/ℓ, or occasionally slightly less. No detailed investigation was conducted to identify the source of those solids. However, it appeared unlikely that overland flow effluent suspended solids concentrations would drop below about 10 mg/ℓ, even under nearly ideal system conditions. Those residual suspended solids are likely a result of microbial cell fragments and organic particles originating on the grass-covered plots.

Removal of influent suspended solids during periods when no influent algae were present, was usually relatively complete. Even under the worst winter conditions, effluent suspended solids concentrations averaged 40 mg/ℓ. Most of those solids were attributed to ineffective removal of the influent solids. This low effluent quality occurred during a period when grass cover was poor, almost one meter depth of snow covered the field, air temperatures were below freezing, and hydraulic loading rates were high (15 cm/week). However, during the nonfreezing periods of the Culver study, when influent algae were not present, effluent suspended solids averaged about 15 mg/ℓ and seldom exceeded 20 mg/ℓ.

The most serious degradation of effluent quality was observed during the summer when lagoon effluent, containing high algae concentrations was applied to the overland flow plots. Effluent suspended solids concentrations averaged 45 mg/ℓ and often were substantially higher. Those solids were primarily algal cells. Two possibilities exist to explain their origin. First, they were the influent cells which passed through the overland flow plot without removal. Second, they were cells which grew on the plot and released to the partially treated wastewater as it passed down the plot. There was no reason to believe the second hypothesis based on observations at the site. For example, the plots were unusually long (80 m) and the lower reaches of the plot were generally relatively dry, a condition not very favorable for algae growth and at a location most likely to release algae into the effluent. A similar observation and conclusion that these algal cells pass through the overland flow process has been reported at Easely, South Carolina (5).

SUMMARY AND RECOMMENDATIONS

Pretreatment for suspended solids reduction in municipal wastewaters prior to overland flow treatment can be limited to gross particle removal. Grit removal and fine screening should be sufficient, and needed primarily to prevent clogging of pumps, pipes and orifices. Unusually high concentrations of grease and oils may cause clogging of the soil at the top of the plot, but this would be unlikely; if prevalent, it would require the use of some type of grease separator.

Removal of algae from lagoon effluents on overland flow systems has not been effective. However, overland flow systems are effective in removing suspended solids from raw wastewaters. Therefore, lagoons should not be used for pretreatment of overland flow influents. If lagoons are needed for wastewater storage during winter or other periods when overland flow systems are less effective, these lagoons should be taken off line and their contents treated before peak algae growing periods.

Overland flow wastewater application systems are either high pressure systems that distribute the water over about the upper one-third of the plot, or low pressure systems that distribute the water over a narrow band across the top of the plot. If adequate screening is provided to prevent clogging of the distributor piping and orifices, suspended solids treatment will be essentially the same. Distribution systems therefore would not be selected based on a consideration of suspended solids reduction in municipal wastewaters. In very high suspended solids wastewaters, some advantage may exist if the suspended solids are distributed over a larger area, as is provided in the high pressure systems.

Grass harvesting procedures are probably more important for controlling suspended solids discharges from clay soils than from sandy soils used with a bentonite seal below the ground surface. Frequent mowing and immediate removal of the clippings will encourage a thick and uniform grass cover, which is best for overland flow treatment. However, more frequent grass harvesting is more expensive. Grass should at least be harvested and removed from the plot before it reaches the height where it falls down. A strong viable grass cover is also important for controlling soil erosion and suspended solids scouring from the plot during intense rainfalls.

The most likely removal mechanism is settling of the influent suspended solids as the wastewater flows down the slope. The settled solids are probably also entrapped at the soil surface and dislodged or scoured loose only during intense rainfalls. Algal cells, which do not settle readily, are not removed effectively by overland flow treatment. However, influent raw wastewater suspended solids, which do settle readily, are removed.

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2. Ketchum, Jr., L.H.; Cunningham, A.J.; Irvine, R.L. Overland flow treatment of poultry processing wastewater in cold climates. Final report grant number R 804677. U.S. EPA, R.S. Kerr Environmental Research Laboratory, Ada, OK. To be available from NTIS.

3. Ketchum, Jr., L.H.; Witherow, J.L.; Cunningham, A.J.; Irvine, R.L. Project summary overland flow treatment of poultry processing wastewater in cold climates. To be published by U.S. EPA, R.S. Kerr Environmental Research Laboratory, Ada, OK.

4. Witherow, J.L.; Rowe, M.L. Meat packing wastewater treatment by spray runoff irrigation. Industrial Waste Branch, U.S. EPA, Corvalis, OR, PNERL Working Paper No. 15, May, 1975.

5. Abernathy, A.R. Personal communication. September, 1980.

Question (by Mr. Steve Belanger): Was your application rate consistent for each level of preapplication treatment? If not, what was the difference?

Response (by Dr. Ketchum): We had widely varying application rates. We tried loadings where we applied water over an 8- or 10-hour period during the day, and rested at night. We experimented with periods of continuous, 24-hour, 7-day-a-week application. A continuous application for 4 or 5 days, followed by a rest of 2 or 3 days, seemed best for our site.

Question (by Mr. Ted Stackley): What percentage of removal did you get in the winter operation with snow cover?

Response (by Dr. Ketchum): We observed effluent suspended solids of 40 mg/l in the winter operation with the influent suspended solids ranging from 100 to 300 mg/l.

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Overland Flow Land Treatment: A Case History at Shafter, California

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Metcalf & Eddy, Inc., in a joint venture with Mason, Wachob & Associates performed a Step 1 Facilities Planning Study for the City of Shafter, which is located approximately 20 miles northwest of Bakersfield in the fertile southern San Joaquin Valley of California. The City currently operates a treatment plant which is old and has operational problems. A draft Facilities Plan was submitted to the California State Water Resources Control Board in November, 1979, which is still being reviewed with no immediate acceptance anticipated. The apparent best alternative project presented in the Facilities Plan was an overland flow land treatment system followed by irrigation of city-owned croplands. This paper presents the preliminary design investigations and considerations which went into the cost-effective analysis of the various alternatives. Also presented is a discussion of the difficulties that may be encountered in obtaining approval of a proposed alternative technology.

STUDY AREA CHARACTERISTICS

The topography of the Shafter area is relatively flat with a uniform southwesterly slope of 0.2% and an average ground surface elevation of 330 feet above mean sea level. The geology consists of an alluvial plain of the Tulare and Kern River formations. Six distinct soil mapping units exist, ranging from clay loam to sandy loam, with three of these units converging on the existing treatment plant property. The area is subject to moderate to severe earthquakes.

The study area is not subject to a flooding hazard from any major surface water course. Localized flooding of stormwater does occur due to the flat terrain and lack of well defined drainage courses, but the treatment plant property is not subject to flooding. The depth to groundwater is at least 200 feet from the ground surface.

Shafter's climate is sunny, warm and semi-arid with an average annual temperature of 65° F, and average extreme temperatures of 36° F in winter and 100° F in summer. The annual average precipitation is 6 inches with 90% occurring in the months of November through April. The months of December and January find the area frequently covered by dense fog which can last as long as two to three consecutive weeks. The annual average evaporation rate is 80 inches.

Most of the study area is under intense agricultural production which precludes much of the natural vegetation and wildlife. There are about 32,000 acres of cultivated farmland in the Shafter-Wasco area with 48% planted in cotton and 14% in almonds. The remaining 38% of the crops consist of alfalfa, milo, nursery, grapes, potatoes, and barley. Oil production is also a significant industry with several active wells on and south of the treatment plant property.

The City of Shafter encompasses about 1,000 acres with a current population of 7,000 which is expected to grow to 8,800 by the year 2000. The City has 250 acres zoned for commercial and industrial land use. The agricultural service industries are the mainstay of Shafter's economy. Agricultural services include potato packing sheds, cotton gins, manufacture of agricultural equipment and pesticides, warehouses, storage areas, and distribution facilities.

EXISTING TREATMENT FACILITIES

The existing Shafter wastewater treatment plant is located about 1.5 miles south of the City's southerly boundary as shown on Figure 1. The plant serves all the development in the City plus Mexican Colony, a residential unincorporated area east of the treatment plant. The City owns 120 acres of land with about 40 acres used for the existing treatment facilities and 80 acres used for the cultivation of cotton. The treatment plant site is surrounded by agriculturally zoned land and the nearest substantial residential development is one-half mile away.

The plant is landlocked and no natural or manmade channels are available for direct discharge of treated effluent. A lease agreement with a farmer whose land abuts the treatment plant allows the farmer use of 80 acres of the City's property for cotton production. In return, the farmer accepts all of the treated effluent from the plant. Therefore, the treated effluent is currently used to irrigate 80 acres of cotton plus a portion of 1,500 additional acres of fiber, fodder, and seed crops owned by the same farmer. The City does not provide any significant storage facilities for the treated effluent so the farmer must utilize the water year-round. The only lease agreement the City could obtain from the farmer allows him to break the lease by giving one year's notice. The farmer is not willing to renegotiate this contract provision. The existing lease agreement, therefore, does not meet EPA or State of California criteria for dependability. A recent survey also showed that no other area farmers were willing to accept the effluent, basically because excellent quality imported irrigation water is currently so cheap.

The existing treatment plant consists of units principally constructed in 1948, but several units still in operation were constructed in 1938. Current flow to the facility averages 0.80 mgd. The plant is a conventional high-rate trickling filter plant without final sedimentation facilities. Sludge treatment is provided by two-stage anaerobic digestion with sludge drying on sand beds.

The existing treatment plant was analyzed and major problems with the mechanical, electrical, and instrumentation equipment were apparent. A major breakdown of the equipment is imminent. Essentially, all process and pumping equipment is, therefore, highly unreliable and needs total replacement.

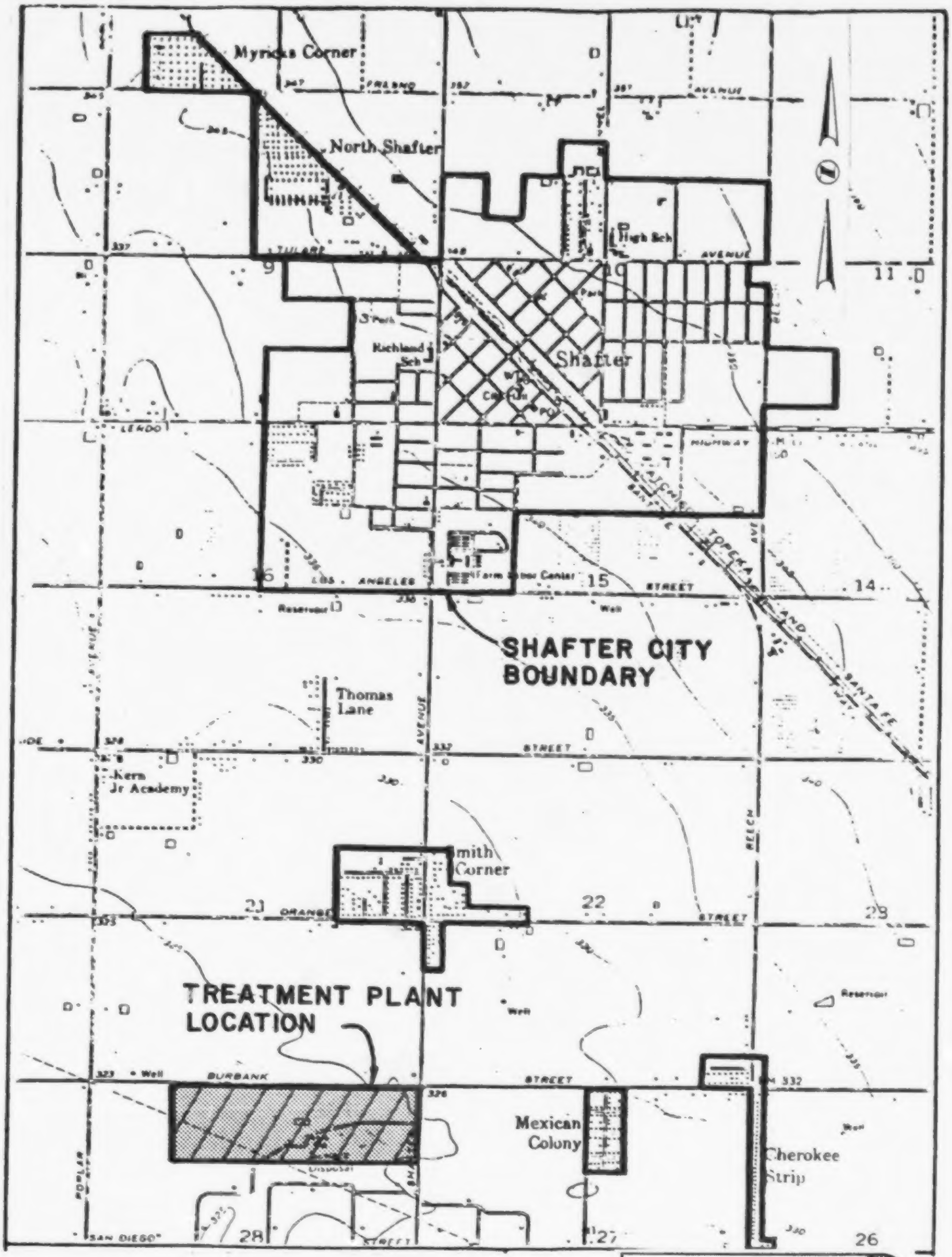

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Figure 1. Treatment Plant Location Plan

The existing anaerobic digestion system has never worked properly. The primary digester is a converted 1938 Imhoff tank. Gas production has never been consistent enough to even heat the incoming sludge. In addition, the primary sludge is pumped to the unit by a converted vertical raw sewage pump, and water must be added in order to pump the sludge into the digester. Therefore, the operation of the existing sludge-handling system has been particularly frustrating for the City.

The plant is currently in noncompliance with its discharge requirements of a median BOD_5 of 40 mg/L. The effluent BOD_5, based on a limited number of samples, has ranged from 20-138 mg/L over the last 18 months with a yearly average of 56 mg/L and a median of 50 mg/L. There is no suspended solid discharge limitation, but a requirement for a median of 0.2 ml/L settleable solids is also not being met.

Regardless of the condition of the equipment, the main process treatment structures are of adequate size to theoretically treat projected loads. This assumes a complete refurbishment of the existing facilities and the required addition of several new facilities to ensure compliance with reliability and discharge standards. The cost-effectiveness of this refurbishment was compared to other alternatives in the analysis that is detailed later in this paper.

WASTE DISCHARGE AND TREATMENT REQUIREMENTS

Current and future waste discharge requirements are issued by the California Central Valley Regional Water Quality Control Board (RWQCB). The RWQCB's basin plan requires the utilization of treated effluent for "beneficial uses." Since agricultural needs are the only major "beneficial use" market for direct reuse of wastewater, discharge requirements for the irrigation of fodder, fiber, and seed crops are appropriate. Table 1 shows the probable discharge requirements issued for the Shafter project.

Table 1. PROBABLE WASTE DISCHARGE REQUIREMENTS FOR IRRIGATION OF FODDER, FIBER, AND SEED CROPS[a]

Parameter	Monthly Mean	Monthly Median	Maximum
BOD_5, mg/L	40	--	80
Settleable Solids, ml/L	0.2	--	1.0
Dissolved Oxygen, mg/L (min.)	1.0	--	--
Coliform, MPN/100 ml	--	50[b]	--

[a] Requirements of Central Valley RWQCB.

[b] If public access precluded no coliform requirement.

All treatment alternatives considered must consistently produce an effluent within the stated requirements, prior to irrigation storage or delivery to a slow rate irrigation system. These requirements have been consistently applied throughout the Central Valley and are the "secondary" treatment levels for facilities with design flows greater than 1.0 mgd as stated in the Region's Basin Plan. It has been the experience of the RWQCB that treatment to the levels stated are appropriate to avoid odor and nuisance conditions during periods of storage and application. Many municipalities in the Central Valley have effluent irrigation contracts with farmers whose objectives are to maximize crop production rather than to provide for continuous, safe effluent treatment/disposal. Therefore, storage facilities are required to provide effluent holding capacity during periods of low irrigation water demands. Also, the RWQCB has found that reclaimed water storage reservoirs containing poorer quality water have a history of causing odors and other nuisances. The RWQCB has not stipulated an effluent suspended solids limit so that pond treatment systems are not precluded from an analysis.

Based upon the probable discharge requirements in Table 1 and the experience of the RWQCB, the following assumptions were made:

1. Land treatment in the form of overland flow shall be preceded by sufficient treatment to protect the distribution and collection facilities from clogging and other related operational problems.

2. Irrigation of fodder, fiber and seed crops for further effluent treatment, disposal and reuse shall be preceded by treatment to a level equal to primary treatment (50 to 100 mg/L of BOD_5) if solely operated by City personnel.

3. Irrigation of fodder, fiber and seed crops for further effluent treatment, disposal and reuse shall be preceded by treatment to a level equal to that in Table 1 if the irrigation system is to be operated by other than City personnel.

4. Equalization or storage facilities shall be preceded by sufficient levels of treatment or shall be equipped with suitable aeration equipment to prevent the production of odors and other nuisances.

SELECTION AND ANALYSIS OF ALTERNATIVES

Evaluation Criteria

Both economic and noneconomic criteria were developed to screen and evaluate various alternative projects. Evaluation criteria included developing economic baseline data for capital and operation and maintenance (O & M) cost estimates and expected revenues from the lease of farmland. The major reference for the costs of land treatment systems was the updated version of EPA-MCD 10, "Cost of Wastewater Treatment by Land Treatment." Significant environmental and social impacts of the project are based on data developed in the environmental setting sections of the facilities plan. Functional characteristics such as flexibility and reliability were also evaluated for each project. The main evaluation criteria by which all projects were judged included the following:

- Monetary cost-effectiveness
- Reliability to meet discharge requirements
- Simplicity and intensity of O & M factors
- Low power and chemical requirements
- Minimum production of waste sludges
- Operational flexibility

Design Flows and Loadings

Existing water use records and wastewater flows were analyzed as a basis for projecting design flows and loadings. Overall domestic/commercial per capita wastewater flows are currently a rather high 115 gcd. Future similar development was assumed to contribute less flow. Only limited BOD_5 data was available, but an analysis showed that the concentrations and unit factors were in the predictable range for a mainly domestic wastewater. The industrial flow contribution is limited to the seasonal operation of three potato packing sheds. The design flows and loadings are summarized on Table 2 below:

Table 2. SUMMARY OF DESIGN FLOWS AND LOADINGS

Item	Amount
Average Annual Domestic/Commercial Flow, gpd	1,100,000
Seasonal Industrial Flow, gpd	60,000
Peak Dry Weather Flow, gpd	2,200,000
Peak Wet Weather Flow, gpd	3,600,000
Average Annual BOD_5, lbs/day	1,720
Average Annual Suspended Solids, lbs/day	1,900

Field Investigation

The applicability of a land treatment process is dependent upon site-specific criteria including the drainage characteristics of the soil, the quality and level of the groundwater, and the subsurface geologic conditions. The 120 acres owned by the City around the existing treatment plant were analyzed in detail to determine the applicability of land treatment. A review of groundwater quality and levels showed no restrictive criteria. Since the U. S. Soil Conservation Service (SCS) soil classifications are valid only to 60 inches, soil test borings were used to determine the areas on the City's property suitable for specific land treatment methods.

Three soil mapping units, as determined by the SCS in a yet unpublished study, converge at the Shafter wastewater treatment facility site as shown on Figure 2. Since the soil boundaries shown are approximate, soil borings were necessary not only to determine subsurface geologic conditions, but also to confirm the surface soil characteristics. Ten soil test borings to a depth of 14.5 to 25 feet were taken in order to prepare a geologic profile cross section.

The soil borings generally confirmed the SCS soil classifications. Silt loam to clay loam soils cover most of the treatment plant property, with estimated permeabilities ranging from very slow to moderately slow. The borings also showed that an impervious clay lens exists below the northeastern 1/3 to 1/2 portion of the site from a depth of about 5 to 14 feet below the ground surface. Therefore, in this area about 40 to 60 acres are suitable for the overland flow process. Soils more suitable for a slow rate irrigation system exist over most of the rest of the property. Only one borehole in the extreme southeastern site corner showed a potential for rapid infiltration.

The field investigation also looked at the feasibility of implementing a land-treatment system. The Shafter area is ideally suited to the use of these techniques. The warm, arid climate allows land application to proceed on a year-round basis. The surrounding area is predominantly agriculturally oriented. Thus, such treatment techniques would be compatible with existing and projected land use patterns. The fact that wastewater has been applied in the area purely for irrigation purposes for more than 40 years demonstrates the acceptance of this technique by the general public.

Viable Treatment and Disposal Options

Based on the discharge requirements for the irrigation of fodder, fiber and seed crops, the small wastewater flows, and the large amount of land currently owned by the City, several relatively unsophisticated, land-intensive treatment methods were identified by the screening process as viable alternatives. All processes except Alternatives 1 and 5 minimize the processing of waste sludge. The processes are summarized in Figure 3. The viable treatment options which underwent detailed cost-effective analysis were:

- Alternative 1 - Refurbish existing treatment facility
- Alternative 2 - Oxidation ponds (anaerobic/aerobic)
- Alternative 3 - Partial mixed aerated lagoons
- Alternative 4 - Overland flow land treatment
- Alternative 5 - Oxidation ditch
- Alternative 6 - Pretreatment by partial mixed aerated lagoons (3 days detention) prior to slow rate irrigation.

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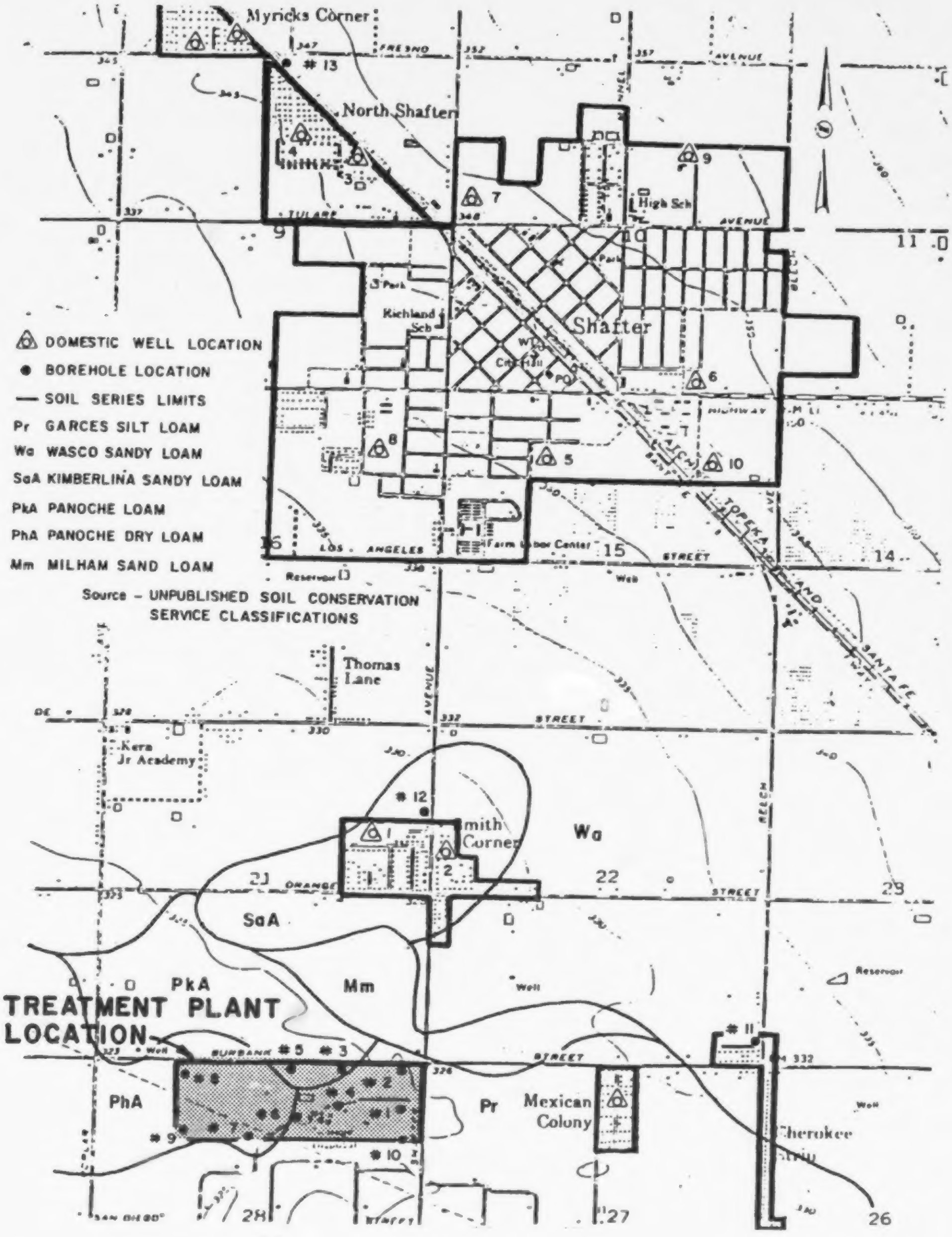


Source – UNPUBLISHED SOIL CONSERVATION SERVICE CLASSIFICATIONS

Figure 2. Soils Map and Borehole Location Plan

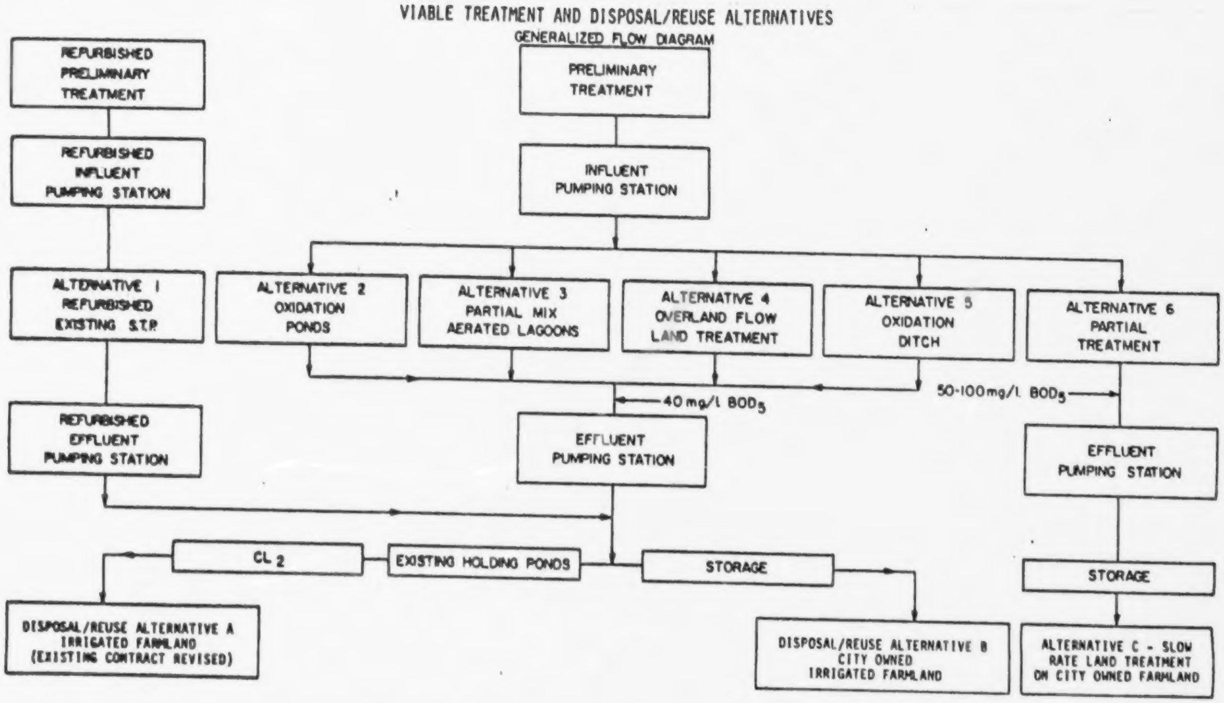

VIABLE TREATMENT AND DISPOSAL/REUSE ALTERNATIVES
GENERALIZED FLOW DIAGRAM
REFURBISHED PRELIMINARY TREATMENT
REFURBISHED INFLUENT PUMPING STATION
ALTERNATIVE 1 REFURBISHED EXISTING S.T.P.
REFURBISHED EFFLUENT PUMPING STATION
PRELIMINARY TREATMENT
INFLUENT PUMPING STATION
ALTERNATIVE 2 OXIDATION PONDS
ALTERNATIVE 3 PARTIAL MIX AERATED LAGOONS
ALTERNATIVE 4 OVERLAND FLOW LAND TREATMENT
ALTERNATIVE 5 OXIDATION DITCH
ALTERNATIVE 6 PARTIAL TREATMENT
40 mg/l BOD5
50-100 mg/l BOD5
EFFLUENT PUMPING STATION
EFFLUENT PUMPING STATION
CL 2
EXISTING HOLDING PONDS
STORAGE
STORAGE
DISPOSAL/REUSE ALTERNATIVE A IRRIGATED FARMLAND (EXISTING CONTRACT REVISED)
DISPOSAL/REUSE ALTERNATIVE B CITY OWNED IRRIGATED FARMLAND
ALTERNATIVE C - SLOW RATE LAND TREATMENT ON CITY OWNED FARMLAND

Figure 3. Viable Treatment and Disposal/Reuse Alternatives

The three effluent disposal/reuse options considered were:

- Alternative A - Renegotiate contract with existing farmer
- Alternative B - Purchase land for adequate disposal/reuse facilities
- Alternative C - Purchase land for effluent disposal/reuse with primary effluent quality irrigation water.

Subalternatives to disposal/reuse Alternatives B and C included production of alfalfa (I) or cotton (II) and for Alternative A, City lease to farmer (a) or City farming the land itself (b). All viable alternatives were given detailed engineering and environmental analyses.

A presentation of the detailed preliminary design criteria for each viable process is beyond the scope of this paper. However, the criteria and units making up the overland flow land treatment train will be briefly summarized. A more detailed description of the proposed system appears later in the paper. Based on a literature review and recommendations in the EPA Land Treatment Manual, it was decided that comminuted, equalized raw sewage flow could be pumped directly to the overland flow treatment plots. The equalization basin would be aerated to prevent odors and provide up to one day's average flow detention time. The overland flow plots would receive an average of 0.75 inches of raw wastewater per day or 5.25 inches per week. This will allow a normal operating time of about six hours per plot every 24 hours. When the plots are taken out of service for harvesting of the grass, slightly higher loading rates will be experienced. The surface area required for the 1.1 mgd design average flow is 54 acres. Runoff collection ditches will collect the treated water and channel it to a pumping station where it will be lifted to storage reservoirs prior to slow rate irrigation. The capital cost components for the overland flow system and their approximate percentage of the total construction cost are shown on Table 3.

Table 3. OVERLAND FLOW CAPITAL COST COMPONENTS

Component	Approx. % of Total Construction Cost
Preliminary Treatment	9
Influent Pumping Station	20
Aerated Equalization Basin	14
Field Preparation	4
Distribution Piping/Pumping	25
Run-off Recovery	2
Service Roads and Fencing	9
Effluent Pumping Station	17
TOTAL	100

A detailed component-by-component capital and O & M cost analysis was performed for each viable alternative. The total capital, operating, and maintenance and total present worth of the viable treatment options are summarized on Table 4.

Table 4. VIABLE TREATMENT OPTIONS, $1,000 (ENR 3500)

Alternative	Total Capital	Annual O & M	Total Present Worth
1. STP Refurbishment	1,819	86	2,739
2. Oxidation Ponds	1,088	46	1,580
3. Partial Mix Aerated Lagoon	1,087	74	1,879
4. Overland Flow	1,459	61	2,112
5. Oxidation Ditch	2,413	94	3,419
6. Pretreatment for Slow Rate Irrigation	888	50	1,423

The STP refurbishment and oxidation ditch alternatives have a significantly higher present worth than the other alternatives and were eliminated from further study. Alternative 6, the pretreatment option prior to slow rate irrigation, predictably has the lowest present worth since it is treating the wastewater to a lower level than the other options. The oxidation pond has the next lowest present worth cost and the aerated lagoon the third lowest present worth. The overland flow system is the fourth lowest cost; however, with the innovative/alternative (I/A) cost preference, the overland flow would be third in the ranking at this point in the analysis.

The next step in the cost-effective analysis was to quantify the effluent disposal/reuse system costs. During the course of the study the City tried to renegotiate their contract with the farmer accepting the effluent to eliminate the contract's one-year-cancellation provision. The farmer would not agree to change his existing lease agreement. Therefore, disposal/reuse Alternative "A" was not feasible. Alternative "A" definitely would have been the least total cost alternative for the City. Since no other farmers were willing to accept the effluent because of concern over losing water rights and the lower cost of imported irrigation water, the only viable option left was to purchase enough land for effluent disposal/reuse for all of the alternatives under investigation. In addition, the City stated that they did not have the interest in or the capability of getting into the farming business (Subalternative "b"), so leasing city-owned land to a farmer for the production of crops (Subalternative "a") was the only viable effluent disposal/reuse option.

Since the City must purchase land for disposal/reuse, enough land should be acquired so that the principal local crop, cotton, could be grown.

Although cotton is less water intensive than alfalfa, it is a more desirable money crop. By purchasing enough land and building a large enough system to irrigate cotton, the City would have a wide degree of flexibility and reliability in its effluent disposal/reuse system and would maximize its appeal for lease to a local farmer. Lease revenues to the City would offset operation and maintenance costs.

The total treatment and effluent disposal/reuse system land requirements and costs were, therefore, key elements in the cost-effective analysis. Agricultural land values surrounding the treatment plant property were estimated to be $2,500 per acre.

Water is lost on the overland flow grass-covered slopes due to evapotranspiration and to percolation. Based on a preliminary water balance, the average yearly amount of water loss is estimated to be 30% with a maximum of 47% loss in the summer and a minimum of 16% loss in the winter. The amount of effluent available for irrigation from the overland flow system is therefore less than for the other viable treatment options. The capital costs, operation & maintenance and land costs for the disposal/reuse system following overland flow would be correspondingly lower.

The magnitude of the preliminary land requirements for the viable treatment and disposal/reuse alternatives with irrigation of alfalfa or cotton are shown on Table 5.

Table 5. PRELIMINARY LAND REQUIREMENTS

Alternative	Total Land Req. (Acres) Storage	Crop Land	Process Facilities	Net Land Purchase Necessary (Acres)[a]
Oxidation Ponds, Alfalfa	73	197	40	232
Oxidation Ponds, Cotton	91	352	40	405
Aerated Lagoons, Alfalfa	73	197	9	199
Aerated Lagoons, Cotton	91	352	9	372
Overland Flow, Alfalfa	65	143	54	184
Overland Flow, Cotton	74	255	54	305
Slow Rate Irrigation, Alfalfa	73	197	2	194
Slow Rate Irrigation, Cotton	91	352	2	367

[a] Total land required minus 78 acres available at the existing site.

In addition to the cost of land, each disposal/reuse system had several capital cost components. These components are summarized on Table 6 which also shows the approximate percentage of each component to the total construction cost.

Table 6. DISPOSAL/REUSE SYSTEM CAPITAL COST COMPONENTS

Component	Approx. % of Total Construction Cost
Storage	20
Field Preparation	10
Distribution Piping	12
Distribution Pumping	30
Tailwater Return	8
Service Roads and Fencing	20
TOTAL	100

The summary of monetary costs, which includes treatment, disposal/reuse, and land costs is shown on Table 7.

Table 7. SUMMARY OF MONETARY COSTS, $1,000 (ENR 3500)

Description	Total Capital Cost[a]	Total Annual O & M Cost[a]	Total Present Worth[a]
Oxidation Ponds	3,742	29	3,568
Aerated Lagoons	3,658	57	3,824
Overland Flow	3,581	45	3,705
Slow Rate Irrigation	3,447	53	3,575

[a] Treatment, irrigation system, and land.

The costs presented are for the irrigation of cotton. O & M costs reflect a credit for revenue generated by the lease of the city-owned property to a farmer with effluent water rights. This lease is estimated to generate income of $83 per acre per year.

The analysis shows that the present worth of the oxidation ponds is essentially the same as for slow rate irrigation. The overland flow alternative is only about 3.5% more expensive than the slow rate system or oxidation ponds. The increased cost-effectiveness for overland flow is the result of the reduced costs for the effluent disposal/reuse system. When the 115% I/A cost preference is applied, both the slow rate and overland flow systems are more cost-effective than either the oxidation ponds or aerated lagoons. It should be clearly recognized that all the treatment alternatives investigated require effluent disposal by land. The costs for such facilities account for a majority of the total project costs.

The nonmonetary and environmental impacts of each alternative were then qualitatively analyzed. Factors included regulatory compliance, implementation ability, public acceptability, reliability, flexibility, environmental, aesthetic and social factors, and resource commitment. Ratings of good, acceptable, marginal, and unacceptable were used for certain impacts, while ratings of enhance, insignificant, slight, moderate, and severe were used for environmental, aesthetic and social impacts. This qualitative rating showed that the overland flow system was ranked number one overall because of its better flexibility, reliability, public acceptability and regulatory compliance. The slow rate irrigation system and aerated lagoons were ranked just slightly lower than overland flow.

An overall rating of all viable projects was then performed which reflects a combination of monetary and nonmonetary factors. Points were given based on the relative importance of each analysis to each other. The weighting was based on input from the City, the general public at a workshop, the regulatory agencies, and the consultants' experience. Monetary costs were given the maximum number of points with a split of 20 for capital costs and 30 for O & M costs. Environmental costs were given 25 points followed by social costs with 15 points and flexibility and reliability with 5 points each. Table 8 reflects the result of this analysis.

The apparent best alternative project for the City of Shafter was the overland flow land treatment process followed by a slow-rate land treatment system sized for the irrigation of cotton on city-owned land. It received 89 points in the ranking of project alternatives; the next closest ranking was for the slow-rate irrigation system with 81 points, followed by the oxidation pond alternative with 80 points.

The overland flow system is an extremely flexible and reliable treatment project. It satisfies all short- and long-term wastewater planning objectives of the City. The process is totally compatible with both local land use and operating skills. It also has a low degree of operating complexity and does not require any sludge processing facilities.

DETAILED DESCRIPTION OF OVERLAND FLOW LAND TREATMENT FACILITIES

The components and operation of the proposed overland flow system are described below. Figure 4 shows a schematic flow diagram of the recommended facilities and Figure 5 shows a preliminary site layout.

Table 8. COMPARISON AND RANKING OF PROJECT ALTERNATIVES

		Alternative Plan Rating			
Factor	Maximum Points	Oxidation Ponds	Aerated Lagoons	Overland Flow	Slow Rate Irrigation
Monetary					
Total Capital & Land Cost	20	15	16	17	20
Oper. & Maintenance Costs	30	30	21	26	28
Environmental					
Land Use	5	5	2	5	3
Soils	2	2	2	2	2
Groundwater	3	3	3	3	3
Scarce Resources	15	15	0	12	10
Social					
Public Acceptability	5	1	2	5	4
Odor Potential	4	1	3	3	2
Personal Income	1	1	1	1	1
Regulatory Compliance	5	3	5	5	0
Operational					
Flexibility	5	2	3	5	4
Reliability	5	2	3	5	4
TOTAL	100	80	61	89	81

Description of Facilities. The proposed overland flow system will consist of three major components: a distribution system, overland flow plots, and an effluent collection system. These components are described below:

1. The distribution system will consist of a pumping station and a network of hydraulically balanced low-pressure pipelines. The pumping station will have sufficient capacity to handle the maximum weekly flow. Flow will be distributed through perforated or gated pipe, or fluted nozzles to evenly distribute the wastewater across the top of the overland flow plots. Utilizing surface application methods is essential to eliminate the possibility of aerosol production.

2. The overland flow plots will consist of a series of slopes constructed "back-to-back" in an undular pattern with an inclination of approximately 2 to 2.5%. The length of the slopes will be approximately 150-160 feet. The slopes will be covered with a perennial grass crop that will serve to prevent soil erosion, provide nutrient removal, and provide the medium for a microbial population on the soil surface. It is this microbial population that is primarily responsible for treatment of the wastewater as it flows down the slopes. The wastewater will be applied at the uppermost end of the plot by surface application and will sheet-flow

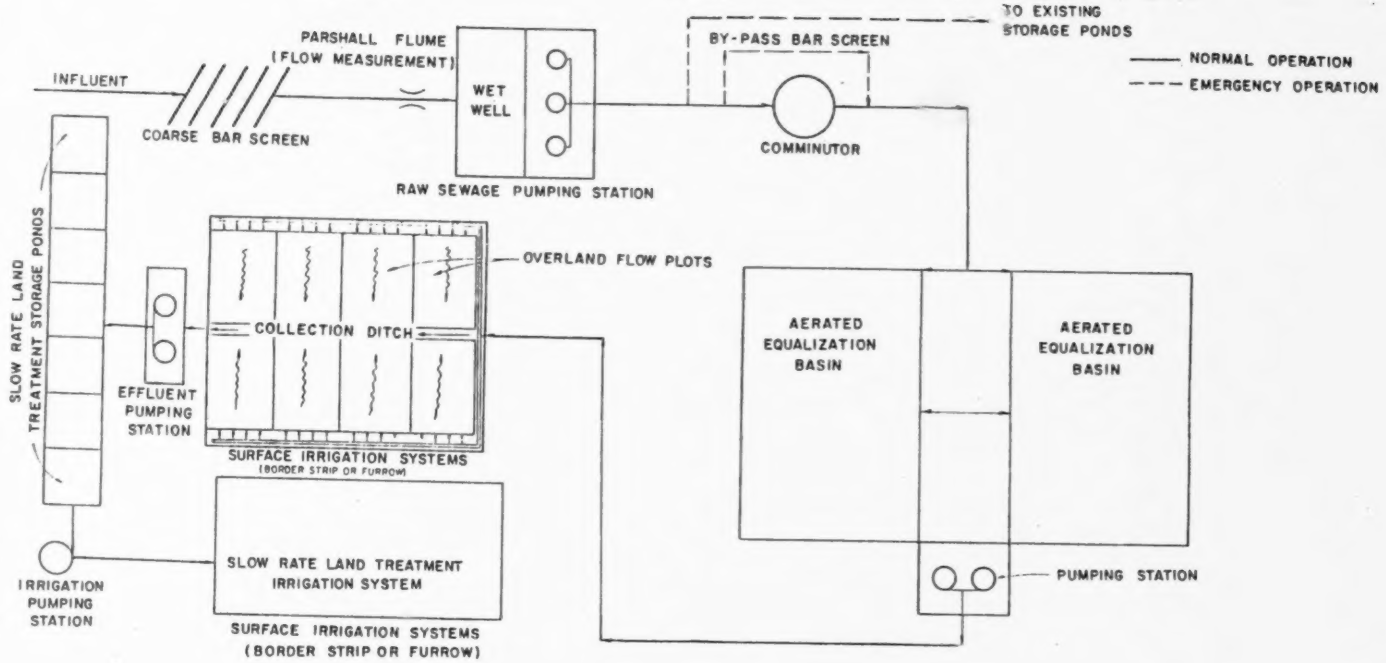

INFLUENT
COARSE BAR SCREEN
PARSHALL FLUME
(FLOW MEASUREMENT)
WET WELL
RAW SEWAGE PUMPING STATION
BY-PASS BAR SCREEN
COMMINUTOR
TO EXISTING STORAGE PONDS
NORMAL OPERATION
EMERGENCY OPERATION
SLOW RATE LAND TREATMENT STORAGE PONDS
EFFLUENT PUMPING STATION
COLLECTION DITCH
OVERLAND FLOW PLOTS
SURFACE IRRIGATION SYSTEMS
(BORDER STRIP OR FURROW)
AERATED EQUALIZATION BASIN
AERATED EQUALIZATION BASIN
PUMPING STATION
IRRIGATION PUMPING STATION
SLOW RATE LAND TREATMENT IRRIGATION SYSTEM
SURFACE IRRIGATION SYSTEMS
(BORDER STRIP OR FURROW)

Figure 4. Preliminary Flow Diagram

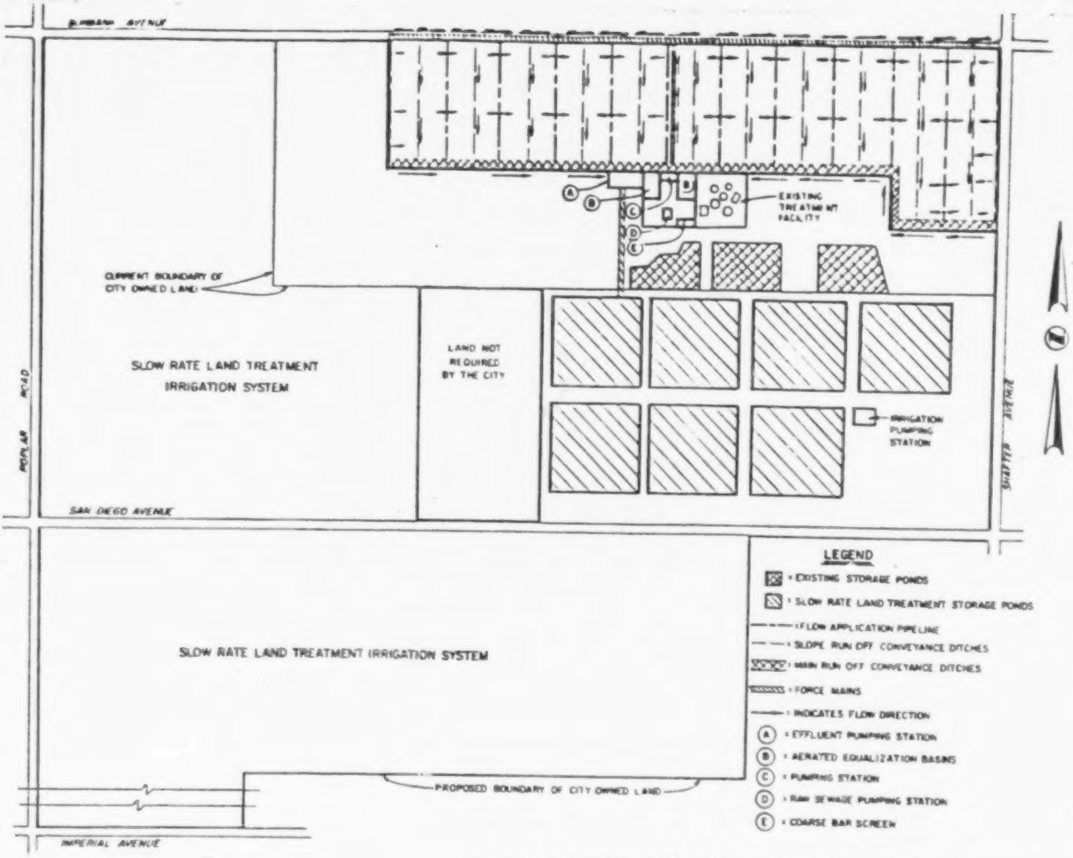

CURRENT BOUNDARY OF CITY OWNED LAND
SLOW RATE LAND TREATMENT IRRIGATION SYSTEM
LAND NOT REQUIRED BY THE CITY
EXISTING TREATMENT FACILITY
IRRIGATION PUMPING STATION
POPLAR ROAD
SAN DIEGO AVENUE
IMPERIAL AVENUE
SLOW RATE LAND TREATMENT IRRIGATION SYSTEM
PROPOSED BOUNDARY OF CITY OWNED LAND
N
LEGEND
= EXISTING STORAGE PONDS
= SLOW RATE LAND TREATMENT STORAGE PONDS
= FLOW APPLICATION PIPELINE
= SLOPE RUN OFF CONVEYANCE DITCHES
= MAIN RUN OFF CONVEYANCE DITCHES
= FORCE MAINS
= INDICATES FLOW DIRECTION
Ⓐ = EFFLUENT PUMPING STATION
Ⓑ = AERATED EQUALIZATION BASINS
Ⓒ = PUMPING STATION
Ⓓ = RAW SEWAGE PUMPING STATION
Ⓔ = COARSE BAR SCREEN

Figure 5. Preliminary Site Layout

over the entire slope. The land requirements for the overland flow slopes are governed by the hydraulic loading rates. The system design for municipal strength wastes is thus independent of the BOD_5 loading.

3. The effluent collection system will consist of a network of ditches and/or drainage pipes at the bottom of each slope to collect the treated runoff. Each ditch or pipe will serve two slopes and will be combined with a system of lined ditches and/or interceptor pipelines to convey treated effluent to a low-lift pumping station and then to the storage ponds. The effluent collection system will also be designed to handle rainfall runoff.

Description of Operation. Screened and comminuted effluent from the aerated equalization basin will be applied to the plots at the rate of about 0.125 inches per hour for six consecutive hours each day, seven days a week. Thus, in a 24-hour period, the application will be rotated over the entire system. This operation will result in a total of about 5.25 inches of wastewater applied per week. During the detailed system design, the possibility of less than 24-hour operation will be evaluated since this could substantially reduce on-call operator time.

Cutting of the cover crop would take place after a thorough drying period (at least one week). During these periods, the application rate would be increased on the remainder of the facilities. This crop would either be removed as green chop and used as fodder or fine chopped and left on the field to decay. In order to minimize equipment purchases, contract arrangements could be made to harvest the cover crop for its cash value.

The refined detailed cost estimate for the facilities is shown on Table 9. The table shows that the overland flow treatment unit accounts for only about 17% of the total project capital cost. The single most expensive unit process is the slow rate irrigation system which also accounts for essentially all of the land costs.

Table 9. OVERLAND FLOW WITH COTTON IRRIGATION
REFINED COST ESTIMATE, $1,000 (ENR 3500)

Item	Cost
Administration & Lab Building	114
Preliminary Treatment & Influent Pumping Station	216
Aerated Equalization Basins	205
Overland Flow System	625
Irrigation System	853
Contingencies	604
Total Construction	2,617
Engineering	393
Land	630
TOTAL CAPITAL COST	3,640

CONCEPT APPROVAL PROCESS

During the regulatory review and approval process of a Step 1 study involving innovative and alternative (I/A) technology, several problems can surface which could prove to be major roadblocks to concept approval. Several of the problems are discussed in this section.

Local Support and Understanding of I/A Technology

The local agency or City must be receptive to and supportive of I/A technology. If a community has a conventional wastewater treatment system and an I/A technology is shown to be cost-effective, education of and marketing to the community may be necessary to have the community accept an I/A technology.

One of the best ways to gain support for an I/A project is to visit a similar project. A similar innovative project may be difficult to find, but fortunately several successful municipal overland flow demonstration and full scale projects were available. The City of Shafter's Director of Public Works, the City Administrator, and two City Councilmen concerned with public works were most anxious to see an operating overland flow system before recommending approval. The Easley, South Carolina facility was visited and the Shafter officials saw the process first hand and talked to the people responsible for operating the system. Based on this single trip, the officials unanimously reported that the overland flow process would meet or exceed their requirements and the City Council voted for the adoption of the process. This experience makes us believe strongly that the EPA's memorandum of May 18, 1979, about the grant eligibility of such field trips is a sound means to gain local support for I/A technology.

Education and Support From Project Evaluators

Project evaluators at the State level can be reluctant to accept an I/A technology due to their unfamiliarity with the concepts or because of the implication to their project success record should the project malfunction. Therefore, the education and support of the project evaluator is more critical for I/A technology. The project evaluators at the State of California Water Resources Control Board (SWRCB) have a large project load and often cannot afford to give an I/A project the time for indepth analysis. They may rely instead on their instincts and experience; hence, in many cases, they will support more conventional alternatives. In addition, cost-conscious water quality control boards may not allow State staff (who review the technical aspects of all projects) to attend EPA-sponsored technology transfer seminars. This was the case in the recent I/A assessment seminars given in Los Angeles.

The project evaluators should be encouraged to visit similar I/A installations with the grantees so they may also gain a first hand understanding and appreciation of the merits of the technology. Without project evaluator support, a project can be seriously delayed or even dropped.

Support of Local Approving Agencies

Local health departments and regional water quality control boards may have even less experience and understanding of I/A technology than do project evaluators. They generally rely strongly on their past experience, mainly with conventional treatment systems. Their education and support of I/A technology is also important.

Local officials are justifiably sensitive to innovative and alternative technology as they have to live with the results. Therefore, they are most likely to want strong assurances for project success. These concerns support the need for the assurances provided for in PL 95-217, Section 202 (a)(3), which allows for a second grant for 100% of the cost of modification or replacement of an I/A system. PL 95-217 also requires that the project must have originally received an 85% Federal grant to qualify for 100% replacement guarantees. In California the I/A funds are currently completely committed; therefore, Shafter's overland flow system, without an 85% grant, would not qualify for the 100% replacement guarantee.

Current Project Status

A situation exists in California where several very large grant projects in the Cities of Los Angeles and San Francisco have approved funding, leaving only limited funds available for the next several years for grant projects elsewhere in the State. This problem, on top of the general overall Federal reduction of Construction Grant funds has virtually left the City of Shafter without hope for Step 2 and 3 funding for the next three to five years due to their lower priority ranking. In addition, the State of California Water Resources Control Board staff, in an effort to reduce treatment plant costs, has challenged the State Regional Water Quality Control Board's discharge requirements as presented in this paper. This interagency conflict has delayed the approval process of the Step 1 Facilities Planning Study and could result in a substantial restructuring and reestimating of the alternatives.

As of this date it is not known when the Shafter Facilities Plan will be approved. Metcalf & Eddy believes the conclusions and recommendations presented in the study are sound and can be further substantiated with additional effort, if required. The issues delaying approval are not environmental concerns, lack of public support, or lack of local funds, but are basically due to a lack of understanding and appreciation for the total project concept of land treatment, which by EPA definition is alternative wastewater treatment technology. This technology is being encouraged by EPA throughout the United States.

In the meantime, the City of Shafter is anxious to obtain report approval, to receive their Step 1 grant payment, and to have the project considered for immediate Step 2 and Step 3 funding. The long delay in the Facilities Plan approval has already cost the City a substantial amount of money due to their 100% financing of the facilities planning costs to date, and inflation will produce further substantial increases in the original total project cost estimates.

ACKNOWLEDGEMENTS

This paper was based on a facilities planning study which is funded by the EPA, the California State Water Resources Control Board, and the City of Shafter. The support of Shafter's City Council, the Director of Public Works (Mr. Lewis Carroll) and the City Administrator (Mr. William Sheldon) is greatly appreciated. The authors wish to acknowledge our joint-venture

partners for this project, Mason, Wachob & Associates, particularly Mr. Rex Mason and Mr. Gerry Claassen. The help of Mr. James Anshutz, Ms. Barbara Derr, and Mr. Ted Elarbee of the San Bernardino Metcalf & Eddy office in this paper's preparation is also greatly appreciated.

Question (by Dr. Robert Smith): Was there any reluctance to accept treatment of raw sewage with overland flow, since this had not been done previously in California?

Response (by Mr. Corneille): This was not an issue. The biggest issues were the squabble between the two agencies about discharge requirements and the general funding limitations.

Question (by Mr. John Overton, ITT Communication Development Corporation, Palm Coast, FL): Would you explain why it was more economical for the farmer to continue to buy water?

Response (by Mr. Corneille): The farmer declined to renegotiate his lease and other farms in the area would not accept the effluent because water is about $10 an acre-foot. The irrigation water is dirt cheap, so why use reclaimed water when you can get water that is cheap?

PB82-194416

Case History - Kenbridge, Virginia

D.D. Deemer, Director - Project Development
Technological Resources, Inc.

INTRODUCTION

In spite of the increased emphasis being placed on land treatment by the EPA and the economic incentives being offered under the Municipal Sewage Treatment Construction Grants Program, there has not been a surge of new projects proposing the use of land treatment. This is especially true for the overland flow process. There are a number of reasons for this, some of which are immediately obvious while others are more subtle.

Although the situation varies from Region to Region within EPA and among various State agencies, there are a number of common problems encountered in promoting the overland flow concept, particularly for use with municipal wastewaters. Some of these problems are specifically associated with overland flow, while others are common to all types of land treatment systems.

Recent experience with a project for the Town of Kenbridge, Virginia has highlighted the difficulties involved in trying to obtain acceptance and approval for the use of overland flow. This project is still in the early planning stages, and a case history at this point in time will not present a complete project story from feasibility study through project construction and start-up. However, a review of the project to date will provide an excellent insight into the preliminary planning required for an overland flow project.

The objective of the following discussions is to simply point out some of the problems that face the engineer who proposes the use of overland flow. Although some suggestions are offered, it is not intended to be critical of either EPA or Virginia regulatory policies and practices. On the other hand, it is intended to show that there are differences between Federal design guidelines and various State regulations, and these differences can present some problems for the designer.

LACK OF FULL-SCALE SUCCESSFUL SYSTEMS

Probably the single largest obstacle to overcome in gaining acceptance of a proposed overland flow system is the fact that there are so few full-scale systems operating in the country today. In addition, of the few overland flow systems that are currently operating, only a limited number are treating municipal wastewaters. The remaining are being used for the treatment of industrial wastewaters. These circumstances present certain problems.

Most regulatory agencies are not likely to readily accept a concept with which they are not thoroughly familiar or which they do not have the opportunity to observe under various operating conditions. Since there are no overland flow systems in the Commonwealth of Virginia, the regulatory officials must go beyond the geographical confines of the State to observe the operation of a system. In the case of Virginia, the nearest overland flow system treating municipal wastewater is the project in Easley, South Carolina. However, it is difficult to observe routine operating performance from such a remote vantage point and since there are not a number of such systems providing reliable performance data, it is only natural to expect a cautious regulatory approach. This particular problem is common in other States also but should lessen as new overland flow systems are approved and more performance data become available.

Another problem associated with existing overland flow systems is a reluctance on the part of regulatory personnel to accept performance data from those systems which treat industrial wastewaters. Understandably, it is often not possible to observe or predict removal efficiencies of certain parameters such as fecal coliform by using data from industrial systems. On the other hand, it is quite reasonable to predict the way a municipal system will react to many different parameters (BOD, suspended solids, nutrients, and many others) based on the performance of industrial overland flow treatment systems.

Although few states have experience with overland flow systems, most have some experience with land treatment in the form of either slow rate irrigation or rapid infiltration systems. Many of these existing systems were designed years ago, before land treatment technology had developed to its current state-of-the-art. Consequently, some of them were poorly designed and operated. These systems have given some regulatory personnel a negative feeling towards land treatment in general.

UNCERTAINTIES IN REVIEWING LAND APPLICATION PROPOSALS

Even though the Municipal Sewage Treatment Construction Grants Program encourages the consideration and use of land treatment systems, many uncertainties exist regarding the expeditious handling of such projects within the grants program. This is due chiefly to the fact that the planning and design of land treatment systems must reflect an interdisciplinary approach, and each system is very site specific. Because of this, somewhat more early planning and site investigation must go into a land treatment project than will generally be required for a more conventional treatment system.

The preliminary stages of most land treatment projects are often best broken into two phases. The first phase is a feasibility study to determine the availability of sites, whether a site can be used for land treatment, and for what type of land treatment the site is most suited. To accomplish the first phase, it is generally sufficient to utilize existing soil maps and a limited number of backhoe test pits or soil borings. The results of this work will allow a conceptual system design to be developed as well as a construction cost estimate. It is generally agreed that all of this work constitutes a study which should be part of the Step 1, Facilities Plan stage of the grants program.

Prior to finalizing a system design, however, additional site investigations must be conducted. For an overland flow system, this includes a thorough contour survey of the site which will allow the designer to develop the size and slope of the individual terraces. A brief hydrogeologic survey should be conducted to ascertain depth of groundwater and its direction of flow, leading to recommendations for the type and location of groundwater monitoring wells. Other tests, such as soil testing to determine quantities of lime and fertilizer to recommend, are also necessary.

For one experienced in the design of overland flow systems, it is recognized that the additional site work should be included as part of the Step 2, Design stage. Sometimes, however, due to a lack of experience with overland flow by the regulatory authorities and a desire on their part to be absolutely sure that the project is both feasible and cost-effective, certain of the design-related tasks are requested prior to approval of the Facilities Plan. It is possible, of course, to perform this work during Step 1, but it places a financial strain on the engineer unless additional funds are appropriated for Step 1. At the present time, there is no clearly defined approach for such cases.

It appears that the types of problems discussed above could be minimized by a closer liaison between the engineer, the state regulatory authorities, and the EPA. Although the situation varies from Region to Region and within individual Regions and various States, there are times when the engineer would benefit from a more active involvement on the part of EPA. After all, it has been the EPA and the U.S. Army Corps of Engineers who have done most of the work with overland flow treatment of municipal wastewaters. However, if those experiences are not passed on directly to the individual States, particularly as they apply to questions being asked by the State regulatory agencies about a specific project, the engineer may have difficulty obtaining project approval at the State level.

STATE REGULATIONS

Over the years, most if not all States have developed and adopted a set of Sewerage Regulations, the purpose of which is to insure that wastewater treatment systems are designed, constructed, and operated in such a way as to protect public health and to meet the water quality objectives established by the State. Although most Sewerage Regulations address the land treatment concept, many do not fully recognize the various differences between the three major types of land treatment, slow rate irrigation, rapid infiltration, and overland flow. Consequently, some of the design requirements for slow rate irrigation, the most commonly used and recognized form of land treatment, are imposed on the other two concepts. This negates some of the advantages that the other systems offer and reduces their cost-effectiveness.

EPA's "Process Design Manual for Land Treatment of Municipal Wastewater" provides an excellent discussion of the differences between the three land treatment types and outlines the various design parameters which have been found to be effective. On the other hand, some of the design recommendations made in the Process Design Manual are not consistent with the Sewerage Regulations adopted by many States, placing the designer in a rather awkward position. This situation was encountered in the Kenbridge project. The following is a brief discussion of some of the chief differences.

Preapplication Treatment

The Process Design Manual recommends that municipal wastewater can be applied to an overland flow system with a minimum amount of preapplication treatment. The Virginia Sewerage Regulations state that the wastewater applied to a land disposal site shall have monthly average BOD and suspended solids levels no greater than 48 mg/l. The use of the term "disposal" is an indication that the land application site is thought of as just that, a disposal site rather than a treatment site.

In the Kenbridge project, it appears that an existing trickling filter system can be used for preapplication treatment. This existing system has historically demonstrated an ability to produce an effluent equivalent to that outlined in the Sewerage Regulations. Therefore, it should be possible to provide a preapplication treatment system consistent with the Regulations with a minimum expenditure. On the other hand, if the trickling filter system did not exist or if for some reason it could not be used, there would be a conflict between the Process Design Manual and the Sewage Regulations.

Disinfection

EPA recommends that disinfection, for overland flow systems, is most effective when practiced on the final effluent, prior to discharge into the receiving stream. The Virginia Sewerage Regulations require that wastewater applied to a land application system shall be adequately disinfected and have a minimum chlorine residual of 2.0 mg/l. In addition, although not outlined in the Sewerage Regulations, the regulatory authorities are considering requiring both pre- and postchlorination for the proposed Kenbridge overland flow system.

This topic generally creates the most concern among various regulatory officials. Their concern over public health and the lack of sufficient convincing data on the health aspects of land treatment systems has caused them to be very conservative concerning the disinfection practices used with land treatment systems.

Storage and Reserve Area

The Virginia Sewerage Regulations require a survey of historical weather data to determine the amount of storage required. If prior climatic data are not used or are not available, a minimum storage period of 60 days is required. An additional requirement of a minimum 10 days backup storage is also imposed.

Coupled with the storage requirements is the requirement that a system have a minimum reserve area equivalent in size to 26 percent of the design field area. This reserve area must be capable of being placed into operation within 10 days.

During the preliminary discussions on these particular subjects, the Virginia Regulations were found to be quite flexible, provided supporting climatic data and sufficient details concerning loading rates and operational flexibility could be shown. It appears that the regulatory authorities will be willing to accept sufficient storage to operate through the worst year of available weather data, or approximately 30 days. It was recognized by the authorities that the requirements for 10 days backup storage and 25 percent reserve field area were developed chiefly as a result of concerns over slow rate irrigation system limitations, and that they were not necessarily appropriate for overland flow systems.

Loading Rates

Overland flow systems have been shown to be effective at loading rates up to 16 inches per week, depending on the level of preapplication treatment. The Virginia Sewage Regulations sets a limit of 2 inches per week for slow rate irrigation systems but does not have a rigid limit for overland flow systems. The chief concern expressed by the authorities was the proposed loading rate which is to be used during intermittent winter operation. Provided this rate is relatively conservative compared to the winter loading rates which have been found effective on other overland flow projects, it appears that it will be acceptable.

Buffer Zones

The conceptual system design recommended a buffer zone of 100 feet beyond the wetted perimeter of the site. This recommendation was based on the fact that the proposed application site is in a rural area and is heavily wooded. The trees will serve as an excellent natural buffer. The Virginia authorities initially recommended the use of minimum 300 feet buffer zones but later compromised with 150 feet, since the site is rural and wooded.

SUMMARY

The overland flow land treatment concept has shown itself to be an effective wastewater treatment alternative for municipal and many types of industrial wastewaters. On the other hand, there is only a limited number of overland flow systems in operation today and those operating on municipal wastewaters are either relatively small-scale or research projects. Although some of these municipal projects have generated a sizeable amount of data, since there is still not a great deal of operating experience with full-scale systems, many regulatory officials are hesitant to approve proposed new projects.

EPA's "Process Design Manual for Land Treatment of Municipal Wastewater" provides the design engineer with a thorough understanding of the different types of land treatment systems and various design parameters for use in designing these systems. The problem facing the designer is that EPA's recommendations are not always consistent with the land treatment regulations adopted by various States. In order for land treatment, and particularly overland flow, to gain greater acceptance, there is a need for a closer liaison between EPA, the State regulatory authorities, and the design engineer.

Question (by Mr. Tom Ellison): I'm a little confused about the cost-effectiveness of overland flow because Mr. Corneille found overland flow to rank third or fourth and you found it to cost about half as much. Would you please clarify this?

Response (by Mr. Deemer): I'm not sure why you should be confused. Cost-effectiveness is very much site specific and project specific. There are a lot of factors that can influence the final cost-effectiveness analysis of a particular land treatment system. I do not find those differences reported by Mr. Corneille and myself surprising.

Additional Comments (by Mr. Earl Smawley, Florida Department of Corrections, Tallahassee, FL): To speak to the cost-effectiveness, we are going to let a contract before the 1st of April for a 1.2-MGD overland flow project. It is definitely going to be costeffective. The cost of the competitive alternative would be about $3 million as opposed to $1 million for overland flow. Another point I want to make is that we are saving about three years by planning and designing the project without Federal funding. Actually, it is not costing the State that much money in terms of a percentage of the cost of the total project. I am probably saving the state of Florida at least three times that amount in avoided inflation costs.

PB82-194424

Overland Flow System: Vinton, Louisiana, Case Study

Kelly M. Peil, Ph.D., P.E.
Roy F. Weston, Inc.

The Vinton case study does not involve operational information because the project is entering the design step of the Construction Grants program. Therefore, this Case Study will be centered around the chronological events for the Step 1 or planning project. This type of presentation is not as easy as one with operational data, but hopefully it will trigger some discussion on how to expedite land application projects. The Vinton project is also of interest because of its Gulf Coast location.

DESCRIPTION OF AREA AND TOWN

The Town of Vinton is located in the southwestern coastal section of Louisiana. This area receives an annual rainfall of 55 inches and approaches freezing temperatures only rarely. Vinton is approximately 9 miles north of the Intracoastal Canal and is only 4 to 5 miles north of the swampy or wetland area along the coast. The groundwater table is less than 20 feet below the surface, with the Town elevation being between 10 and 15 feet above sea level. The major soil associations are the Morey-Beaumont and Mowata-Crowley series. These soils are very slowly permeable.

Vinton has a current population of approximately 4,000 with a design population of 5,800 in the year 2001. We will discuss the importance of population projection later. The people of Vinton are farmers, race track employees, and employees of nearby petrochemical industries. The paper industry and Intracoastal Canal also provide employment.

The surface water in the area consists of the Vinton Navigation Canal and its tributaries. The Canal is tidal from the Gulf to Vinton. The Canal has been designated for use as secondary contact recreation and fish and wildlife propagation. In Louisiana, this means that chlorination is not required but the coliform level in the stream must not exceed 1000 MPN/100 ml. This will affect the design of the treatment system and will be discussed later. The 100-year flood plain is within the banks of the Canal and its tributaries.

The Vinton sewage treatment plant was built in 1960 and is a spiragester-trickling filter plant. Over the years, the deteriorating collection system has created grit problems in the lift station. In addition, the infiltration/inflow problems have caused overflows, backups, and hydraulic overloads at the plant. The Town has outgrown the design capacity of 0.4 MGD. The discharge of the existing plant is into the Vinton Navigation Canal which enters the Intercoastal Waterway. National Pollutant Discharge Elimination System (NPDES) permit limits are 30/30.

Because Vinton outgrew its treatment plant, it was decided to enter the Construction Grants Project. Mr. Fred Smith was the Vinton Town Engineer at that time and subcontracted a portion of the project to Roy F. Weston, Inc. The following table outlines the milestones of the project from initiation to the present time.

Table 1
TOWN OF VINTON
CONSTRUCTION GRANTS PROJECT

Item	Date Initiated	Date Completed
Step One Grant Application	Sept., 1976	----
Grant Acceptance		Mar., 1977
Infiltration/Inflow	Mar., 1977	July, 1977
Approved		Sept., 1977
Sewer System Evaluation Survey	Oct., 1977	June, 1978
Approved		Oct., 1978
*Facility Plan	Mar., 1977	June, 1978
Approved		Aug., 1980
*Environmental Assessment	Mar., 1977	June, 1978
To State/EPA	Aug., 1979	July, 1980
Step Two Grant		
Rehabilitation	Apr., 1979	Apr., 1980
Treatment System	May, 1980	Sept., 1980
Step Three Grant Segment	Aug., 1980	----

*See Table 2.

The project started with the Step 1 grant (see Table 1) applicacion in September, 1976. The grant offer was accepted in March, 1977. The program consisted of sewer rehabilitation, replacement of septic tanks with sewers, and a new sewage treatment plant. The Infiltration/Inflow Analysis determined a Sewer System Evaluation Survey (SSES) was cost-effective, and these two reports were approved in September, 1977 and October, 1978 respectively. The Facility Plan and Environmental Assessment began in March, 1977, but were delayed because of the SSES.

A more detailed breakdown of the Facility Plan/EIA is seen on Table 2. Once the design flows were approved in October, 1978, the two documents were sent to the various environmental agencies for review, and a public hearing was scheduled for January, 1979. The hearing created more delays, as will be discussed later, and a second public meeting was held in April, 1979. The reports were submitted to the State and U.S. Environmental Protection Agency (EPA) in August, 1979 and finally approved August, 1980,

Table 2
TOWN OF VINTON
CONSTRUCTION GRANTS PROJECT

Item	Date Started	Date Completed
Facility Plan/EIA	Mar., 1977	Jun., 1978
Awaiting SSES Approval		Oct., 1978
Submitted to Required Agencies	Dec., 1978	-----
Public Hearing		Jan., 1979
Utica Trip		Feb., 1979
Town Approval		Mar., 1979
Public Meeting		Apr., 1979
Sent to State	Aug., 1979	Apr., 1980
EPA Approval		Aug., 1980

During this time some Step 2 work was proceeding. The rehabilitation specifications began in April, 1979 and were approved by the State in August, 1980. The Step 2 and Step 3 Segment Grants were submitted and approved by the State. Not all Step 1 projects take four years; some may take longer. A great deal of time was spent in review and rule changes during that time. Unfortunately, when the rules changed, all supportive documents had to be changed. These delays are discussed more fully after further information on the Vinton treatment system has been presented.

WHY OVERLAND FLOW

Four treatment alternatives were evaluated for Vinton which included: 1) trickling filter plant expansion, 2) a new mechanical plant, 3) a new 3-cell lagoon, and 4) an overland flow system. Actually, the land application alternative was subdivided into 3 alternatives which involved overland flow after partial treatment in the existing plant, application of raw wastewater, and overland flow after a single-cell lagoon.

Normally, the most practical wastewater treatment alternative would be an expansion of the existing plant. However, since we are discussing a Louisiana project where three-cell lagoons are popular, this probably would have been the cost-effective alternative. But land application had to be evaluated as an alternative, and in 1978 the alternative received special emphasis from EPA with the 85% funding and 15% break given to the cost-effective evaluation. In fact, after the alternatives were costed, the cheapest was the three cell lagoon but with the 15% break; the overland flow system with a single-cell lagoon was the selected alternative.

DESIGN OF OVERLAND FLOW SYSTEM

As is recognized, overland flow is one of three land application systems. A Facility Plan must consider all three systems, but for Vinton the choices were quickly narrowed to one, due to the slowly permeable soils and 55-inch rainfall per year. Although the EPA design manual describes several procedures to follow for the selection of a land application system, most of these apply to slow or high rate systems. The type of soil available in the areas of town where land was available was the most important criterion for Vinton.

Once the type of land application system is selected, the engineer must select the pretreatment system, if any, need for storage, the application rate and frequency, the distribution system, the terrace configuration and slope, the cover crop, and the need for posttreatment or disinfection. Utilizing available literature information, we selected conservative design criteria. At this time, the State of Louisiana had no written criteria. However, after we informed the State office of our desires, the office prepared a statement which was even more conservative. (Table 3 lists our design criteria basis.) The State in May, 1978 wanted to see 2 inches/week and pretreatment.

Table 3
TOWN OF VINTON
DESIGN CRITERIA

Item	Unit
Design flow (average annual)	1 MGD
(peak)	2.5 MGD
Field area	
application	70 acres
buffer	40 acres
Water balance	
annual precipitation	55 inches/year
evapotranspiration	50 inches/year
Pretreatment	Single-cell lagoon
Organic loading	
to lagoon	990 lb/acre/day
to land	10 lb/acre/day
Nitrogen loading	1300 lb/acre-year
Phosphorus loading	200 lb/acre-year
Application rates	
length of operating season	50 weeks/year
application period	8 to 18 hours/day
rate	4 inches/week
Storage capacity	20 MG

The State later revised their criteria and in May, 1979 accepted an application rate of 4 inches per week, a maximum of 10 days storage, pretreatment with either an aerated lagoon or single-cell pond, and measurement of discharge flow; chlorination was not necessary under normal conditions.

It is important, therefore, to confirm the State's design criteria early. This should be common practice for most engineers, and I assume by now all States have design criteria available for land application. Every aspect of the design should be confirmed with the State before engineers proceed too far and lose money with changes and jeopardize their reputation with the client. Some States like Texas will simply reply, "Review our guidelines and if your engineering judgment results in some modifications, present them to us and we will consider them on a case-by-case basis."

Any new sewer work is a critical item in the Construction Grants Program. The eligibility rules must be clarified; hopefully they won't change before the report is approved. This was a significant problem in the Vinton case.

Before discussing any problems in detail, I will describe the initial design of the Vinton system. The sewage would continue to be collected at the main lift station located on the south side of town. The station would have two new pumps added to handle a design average flow of 1 MGD with a peak hydraulic flow of 2.5 MGD. A 12-inch cast iron force main would transport the sewage approximately 6,000 linear feet into a 23-acre, single-cell lagoon. A screen would be placed at the discharge to keep large solids out of the lagoon.

The lagoon would provide primary treatment of the sewage. The water level would be variable with the normal treatment level being 2.5 to 3 feet deep. An additional 2.5 to 3 feet would be available for wet weather storage. The 23 acres of water provides approximately 20 days detention for treatment and 20 days for storage. This variable level operation is also beneficial for weed and mosquito control. In addition, the 1 MGD flow may be applied during an 8-hour day at a rate of 3 MGD while it is stored during the remaining 16 hours per day.

The water from the lagoon would be pumped into the distribution system. Approximately 70 acres of land are required at an application rate of 4 inches per week. The site would be divided into six terraces in a back-to-back configuration. A 2-percent slope would be constructed. A header would split the terraces, with a lateral extending down the center of each set of terraces. Runoff collection ditches would be constructed at the end of each terrace. All ditches would converge into a central chamber where the flow could be sampled and measured.

Initially, the water would be applied with stationary rotating sprinklers on risers at the center of the terraces. Thereby a 50-foot radius of water would be applied to two terraces at a time. We felt that the water would be applied evenly on the top of the terraces and flow in a thin sheet down the remainder of the terrace.

The cover crop was alfalfa because of the race track's need for hay to feed the horses. This was later changed to coastal bermuda because of the much greater nitrogen uptake. Also, the bermuda produces a very nutritious hay and grows year round until freezing temperatures.

Finally, chlorination was not included because of the Louisiana decision to eliminate it where the receiving stream was not used for contact recreation or drinking. The effluent limits for the receiving stream remained 30/30; therefore no further treatment of the effluent was necessary.

PUBLIC INVOLVEMENT

As we presented earlier, this Facility Plan was completed in June, 1978. The plan could not be finalized until approval of the SSES and review by wildlife agencies, etc. A public hearing was held in early January, 1979. The hearing was well publicized as evidenced by the standing-room-only audience. The transcript from the hearing required more pages than the Facility Plan.

Various adverse comments were received by the Mayor during the advertising period. In anticipation of an encounter with negative feelings toward land application, Mr. Dick Duty was invited to attend the hearing.

Briefly, the meeting started with the usual introduction, purpose of the hearings, and summary of the Step 1 program and the treatment alternatives evaluated. Considerable detail in the selected plan and how an overland flow system operates was presented. Also, slides were presented of other land application sites. The floor was opened for comments and questions. There was not one vocal member of the audience in favor of the system. By the time the meeting had lasted two hours, only two people were in favor of the system: Mr. Duty and myself. The people felt the Town was going back to the days of open sewers. The lagoon was termed a cesspool. The total system would create odors, mosquitos, deadly aerosols, and would contaminate the ducks which land on the "cesspool."

The leading opposition came from a person who owned the adjoining property. The site at that time was south of Vinton. The owner was not a voting resident of Vinton. One man even offered to pay for the system if it did not smell. It became clear that the public was uneducated on these types of sewage treatment plants and were quickly swayed by someone using scare tactics.

By the time the meeting was over, the Town Council felt it best to reconsider the plan. To assist with the decision, we planned a trip to Utica, Mississippi, the closest municipal overland flow system.

Between the public hearing and the Utica trip, the Mayor and several councilmen had a meeting with their congressman and Mr. Cahill and Mr. Thomas of EPA, Washington, D.C. The Land Treatment Task Force convinced the Town to continue to pursue the land application alternative and pledged their support. EPA felt the Utica trip was a good idea and they financed 75 percent of it.

Fifteen residents of Vinton took the bus trip to Utica. On the way, we stopped at the Vinton plant and two lagoon systems. Most of the residents had never been to the Vinton plant. The odor was noticeable. The two single-cell lagoons comprised the treatment plants for the two small towns. Both were well operated, neat facilities. At Utica, the U.S. Army Corps of Engineers (COE) made a presentation; everyone had ample time to ask questions, observe, smell, and touch the system. Each member left the site reassured.

A second public meeting was scheduled for early April, just before the sales tax vote that would finance Vinton's portion of the project. We had by this time selected two other sites for the treatment system and changed from spray to surface distribution. At the April meeting we presented slides from the Utica trip, a movie which Mr. Duty brought, and most importantly, the 15 people who had made the trip gave positive testimony for the project. The same negative people from the previous meeting were present again and brought up the same testimony. However, the people who had visited the site responded to some of the points, and we asked for documentation of the negative points. As a result, the crowd turned in favor of those who visited the site. The Town Council voted in favor of the plan. The measure passed by a 6 to 1 margin in favor of a 1% sales tax.

THE REGULATORY REVIEW

Since the April meeting and the change in design, the east Vinton site was selected. The EIA and FP were changed and submitted to the State in August, 1979. During the eight months that elapsed before State approval, the State of Louisiana had many internal problems and priority list problems with EPA. To make a long story short, the engineer and/or Town must let the regulatory agencies know that there is someone who cares about a project. Constant pressure may move a project from a stack to a desk for review. The engineer should call for a meeting to walk through the plan with the reviewer. Most questions can be answered on the spot.

While the Step 1 documents were being reviewed by EPA, we were preparing the Step 2 proposals and grant applications. There was some initial problem with the interpretation of the rules for a Step 2/3 grant, which would allow the land for a land application project to be purchased early. A system cannot be designed if there is no land, and the discrepancy concerned the 2 million dollar cutoff--whether related to eligible or ineligible dollars.

During this same time, the eligibility of collection sewers was changing. The initial interpretation of eligibility involved a percentage of flow due to the residents before 1972. However, this changed to the present 2/3 rule which says the sewers are eligible only if 2/3 of future flow is due to residents before 1972. This eliminated the majority of Vinton's new collection system because the areas where septic tanks are utilized are the areas which will continue to grow. In 1978 and 1979, the residents were led to believe that several of them would be on sewers rather than septic tanks. They voted for the sales tax increase for new sewers. Now the engineer and Town Council look bad because the project has lost close to a million dollars in sewers.

This loss of sewers, however, lowered the eligible cost of the project from 2.6 to 1.6 million so a Step 2/3 Grant was submitted and was rejected several months later. The application was changed to a Step 2 for design and a Step 3 segment for the cost of land only based on PRM80-3--in other words, two grants to accomplish the same purpose as one.

The National Environmental Policy Act (NEPA) office was reviewing the EIA during this same time (the State does not review this document). The review resulted in nine problems which would either change the system design or destroy the project. The NEPA branch has acquired the authority to review the EIA not only from an environmental standpoint but also from an engineering standpoint. The engineer must address the following topics early in the project or he could lose the project.

The 1980 population projection guidelines overruled those of 1978 and said Vinton, and for that matter all of southwestern Louisiana, was not growing. Electrical, water, and sewer connections indicated growth; yet someone decided to base the decision on one piece of information which said there was no growth. As a result, we compromised on a 2001 population of 900 less people to be reviewed at a time when the 1980 census information was actually available. It is clear that if the design population changes significantly, one could be starting a project over.

A new definition of potential wetlands was implemented and the site had to be inspected by the COE for indicative species. U.S. Geologic Survey maps are not good enough to make this determination. A project could be in trouble if the COE were not contacted early. This site proved to be nonwetlands.

The single-cell pond was too large with respect to its use as a storage facility. Other locations in southern Louisiana were only using 7 days storage rather than 20 as in our case We argued this objection citing the public's concern with odors, etc. The conservative and flexible design was believed more important than following other paths.

Another item considered was the requirement for disinfection of effluent. Although the State does not require chlorination for effluent into the Navigation Canal, the water quality limits must not exceed 1000 MPN/100 ml. There are no data that say an overland flow system can routinely achieve a fecal coliform level below 1000 MPN/100 ml. If a disinfection system had been costed in the land application alternative, we would be discussing the Vinton three-cell lagoon system at another conference, We agreed to monitor the receiving stream after the system was online, and if the fecal coliform level increases, we will add a UV disinfection system. Provisions for the system will be included in the design project.

We also had to obtain medical proof that the Vinton area had been subjected to waterborne diseases. This was to document health problems possibly due to septic tanks. This information can be obtained from the State Health Department for as far back as records are kept. And yes, that area of the State did have medical problems with amebiosis, hepatitis, dysentery, and paratyphoid.

I am sure everyone here who has worked on a Construction Grants Project has had similar problems and some worse than these. I could go on, but the problem narrows down to a lot of time and money spent on a Town of 4,000 people who need a new sewage treatment plant. The engineer must be concerned with the Town's needs and the most economical and environmentally sound method to achieve those needs. However, there must be a happy mean where the rules and regulations work with the engineer to expedite a project. The present rules and regulations were not prepared with an emphasis on land application. One of these problems is the purchase of land. A small town does not have the capital to buy several acres of land. Hopefully, PRM80-3 will solve this problem. It is not good politics for a town to condemn existing property for siting a new project.

CURRENT PROJECT STATUS

Presently, the Step 2 and Step 3 segment grants for treatment design have been approved by the State and no problems have arisen from EPA. The land has been appraised by two appraisers, and negotiations are underway for purchase. The system will be designed with a single-cell lagoon, gated pipes, 4 inches per week, 2% slope, and variable hours of application. A building will house a lab, office, shop, and public information room. The design should be complete by the end of 1980 and the facility under construction in late 1981.

In conclusion, the Vinton project began in 1976 as the first overland flow system in coastal Louisiana. Four years later, it is just into design. The State refined its guidelines using the Vinton project. Others have learned from the project. There is an urgent need for health effects data, more Federal operational data, and more public information material. Equally important, the regulatory agencies must decide if they really want to stress land application. If the answer is yes, the first level review personnel must be encouraged to look for errors, missing information, and environmentally damaging projects. But they should use judgment in the amount of time and money spent on items that delay the project and end up costing more money than they are trying to save.

Question (by Mr. Rick Hunt): Why did you provide a 20-day detention time in the lagoon when Louisiana requires only 10 days? Was this just a safety factor?

Response (by Dr. Peil): There is a 20-day detention time for treatment and 10-day storage time. The 10 days of storage requirement complies with the State guidelines that are now in draft form.

Question (by Mr. Rick Dedman, John Hayes & Associates, Nashville, TN): Did you find the delays with this project any greater than with any other Construction Grants project?

Response (by Dr. Peil): Yes. We have handled many Construction Grants projects, and this land application project did experience more delays than most. We had to have two public meetings; the municipality lost confidence; and we had to reconvince the town that it was a good system. I don't think these delays would necessarily be true for somebody starting today.

PB82-194432

Overland Flow System Application at Heavener, Oklahoma, for Treatment of Domestic Wastewater

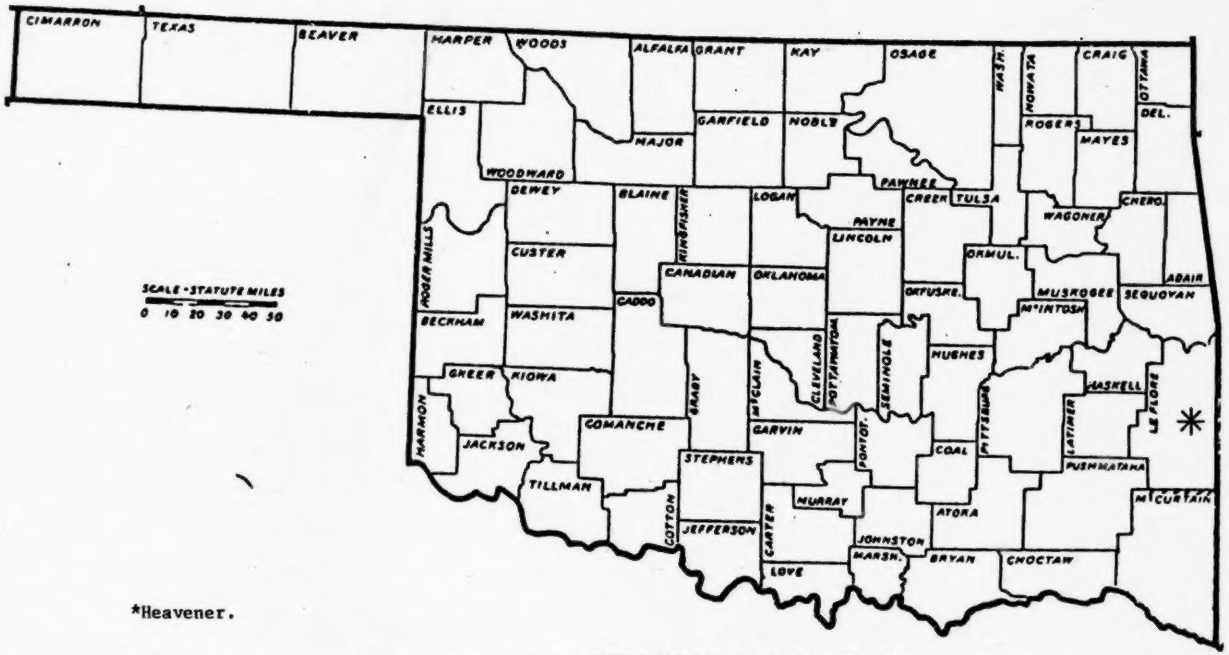
Jimmie M. Alford, Consulting Sanitary Engineer
Alford Engineering Company
Hot Springs, Arkansas

The purpose of this paper is to enumerate and discuss the factors that have influenced the selection of overland flow land treatment as the most cost-effective waste management practice for the community of Heavener, Oklahoma.

Since the first publication of needs surveys and the development of priority lists for the distribution of Federal moneys under P.L. 92-500 and P.L. 95-217, Heavener has been identified as needing improved waste treatment processes for two municipal discharge points and associated urban runoff. In 1975, this firm was retained to provide technical and engineering advice leading to implementation of best practical waste treatment technology. Since that time, a wide range of alternatives have been investigated during the conduct of the Step I, or facilities planning, project.

The existing collection and treatment system consists of approximately 11 miles of 6- through 15-inch gravity sewer lines and two treatment plants. There are no pumping stations or force mains in the system. The earliest flow analyses showed the need for a sewer system evaluation survey to determine the sources and quantities of removable infiltration and inflow to reduce the volumes of intruding surface and ground water. There was also a public outcry to stop the frequent overflowing of manholes and outlets and the bypassing of raw sewage from the installed treatment processes. The cost-effectiveness comparisons between transportation and treatment necessarily involved a calculation of best treatment technology and selection of low-cost operations to reduce the long-term investment of local expenditure. Thus began the long and deliberate evaluation of alternate treatment technologies that would satisfy the water quality objectives, provide best protection for the environment and downstream users, enhance the widest range of future uses, conserve the natural resources, and require the least commitment of the life cycle financial and human resources.

In this particular setting, the residents of Heavener and approximately 900 rural users depend on the local water treatment plant for potable water. The discharges from the waste treatment plant and untreated urban runoff (including waste from overflowing manholes) follow Oil Branch Creek southward to its confluence with the Poteau River only eight miles above the surface intake for the potable water system. Dilution, natural purification and conventional water treatment processes are hardly sufficient to guarantee the necessary degree of protection to life and health for the residents of the area. Ultimately, these discharges reach Wister Reservoir, which serves as recreation, flat water sports, fishing, and water supply for several thousand residents of four counties in southeastern Oklahoma. (See Figure 1 - Map of Oklahoma, LeFlore County and Heavener marked as a star.)



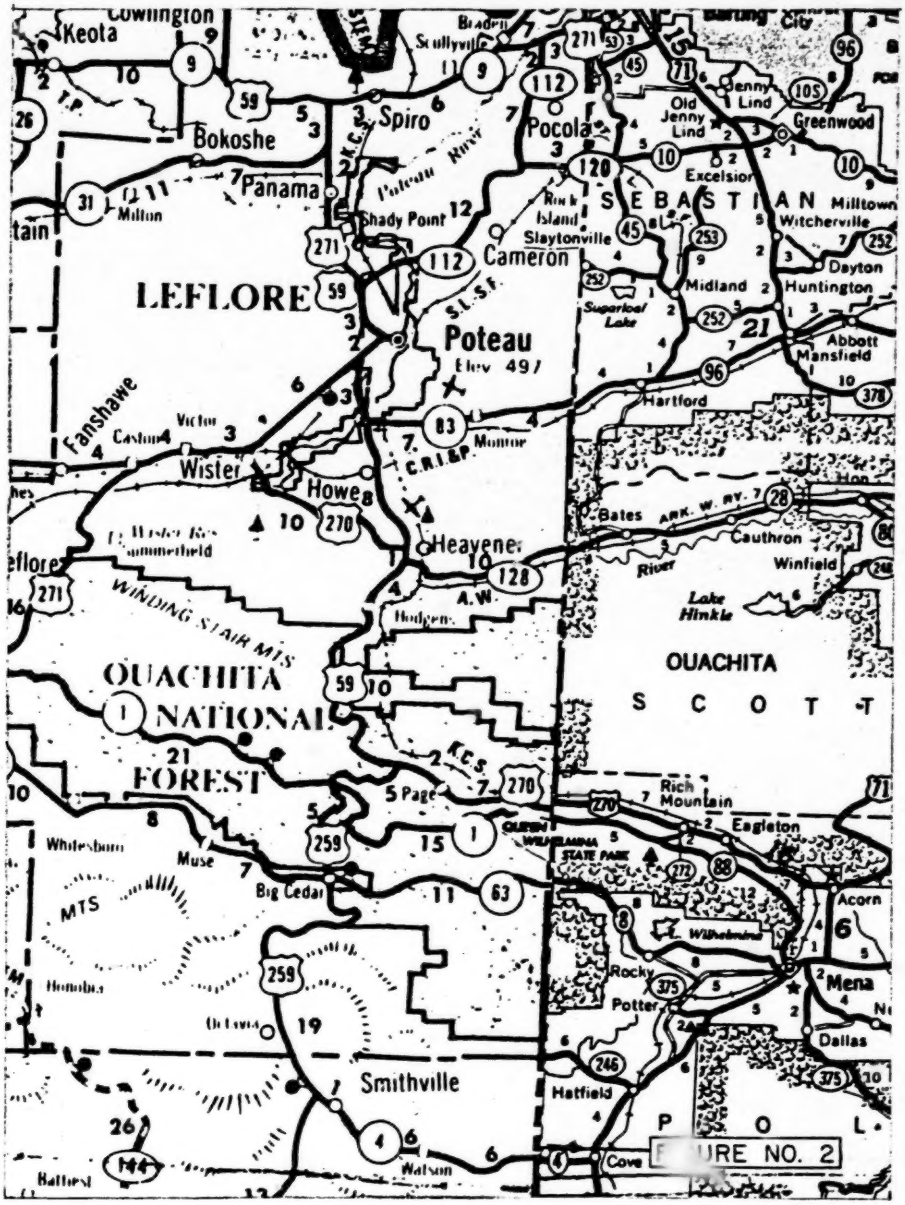
*Heavener.

Figure 1. Oklahoma.

Heavener is a community of about 2,700 persons located in south LeFlore County, Oklahoma, approximately two miles north of the Poteau River, and has recently gained notoriety for the excellent hang gliding conditions and launch facilities of Poteau Mountain, which was the site of the 1977 National Competition of this rapidly growing sport. Other attractions include the Heavener Runestone on which is carved the markings of the earliest white visitors to the area approximately dated early 11th century. The proximity of the Ouachita National Forest, Lake Wister, and the uncluttered vistas of the Talimena Skyline Drive serve to attract thousands of visitors annually to the immediate area. (See Figure 2.) This sector of Oklahoma has proven reserves of high-grade anthracite coal important to this nation's economic future. The overall growth potential and the associated environmental concerns have been brought into sharper focus as the community deals with health and water quality problems of the future, while facing the financial commitment required in a substandard economic climate existing in the recession of 1980.

The Heavener sanitary waste flow is discharged from two plants shown in Figure 3. The main sewage treatment plant is a 0.25 mgd trickling filter plant constructed in 1962. The plant has been reasonably maintained but has generally produced effluent not quite meeting the national standard of 30 mg/l BOD and total suspended solids (TSS). The plant has been frequently bypassed due to hourly peak flows exceeding twice the design flow and when associated with wet weather flows or mechanical malfunctions. Biological overloading has not been a particular problem, though there have been incidents of waste oil discharge that have damaged the effectiveness of the trickling filter. Figure 4 depicts the flow schematic of the existing plant. Another plant exists for the benefit of about 250 residents in the northwest part of the community. This plant utilizes conventional lagoon technology and presently discharges into Coal Creek and the Poteau River below Wister Reservoir. Based on the facility planning conclusions, this lagoon will be utilized for sidestream flow equalization, partial pretreatment, and effluent pumping into the collection system of the main plant for single point treatment and discharge.

Determination of effluent quality limitations posed some problems. There are two agencies which have published authorized Section 208 Water Quality Management Plans, namely, the Oklahoma Department of Pollution Control and the Arkhoma Planning Commission which has jurisdiction over LeFlore County. There were differences in the published figures for authorized population projections and the design projections authorized by pertinent U.S. Environmental Protection Agency (EPA) regulations. Figure 5 tabulates some of the significant organic and hydraulic calculations which affected the design wasteload allocation. Some of these discrepancies were never resolved, and it became apparent that while a discharge quality limitation of 20 mg/l BOD and 30 mg/l TSS could be approved, the actual wasteload allocation would require the discharge of a substantially higher quality wastewater unless the total hydraulic load could be reduced. Since it was impractical to eliminate all the infiltration/inflow and resort to flow reduction techniques and conservation, it became necessary to carefully evaluate processes which could produce better than secondary effluent and stand the scrutiny of advanced waste treatment cost comparisons. In the process of comparing the economics and capabilities of the various treatment processes, it was determined that physical/chemical treatment, biological and mechanical process combinations,


Cowlington
Keota
Spiro
Bokoshe
Pocola
Panama
Milton
Shady Point
Cameron
Rock Island
Slaytonville
LEFLORE
Poteau
Elev 497
Fanshawe
Castor
Victor
Wister
Howe
Monroe
Heavener
Wister Res
Summerfield
Leflore
Hodgens
WINDING STAIR MTS
OUACHITA
NATIONAL
FOREST
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Whitesboro
Muse
Big Cedar
MTS
Honobia
Octavia
Smithville
Watson
Battiest
SEBASTIAN
Old Jenny Lind
Jenny Lind
Greenwood
Excelsior
Milltown
Witcherville
Dayton
Huntington
Midland
Sugarloaf Lake
Hartford
Abbott
Mansfield
Bates
Cauthron
Winfield
River
Lake Hinkle
OUACHITA
SCOTT
Rich Mountain
Eagleton
QUEEN WILHELMINA STATE PARK
Acorn
Wilhelmina
Rocky
Potter
Mena
Dallas
Hatfield
Cove
POLK
URE NO. 2

Figure 2.

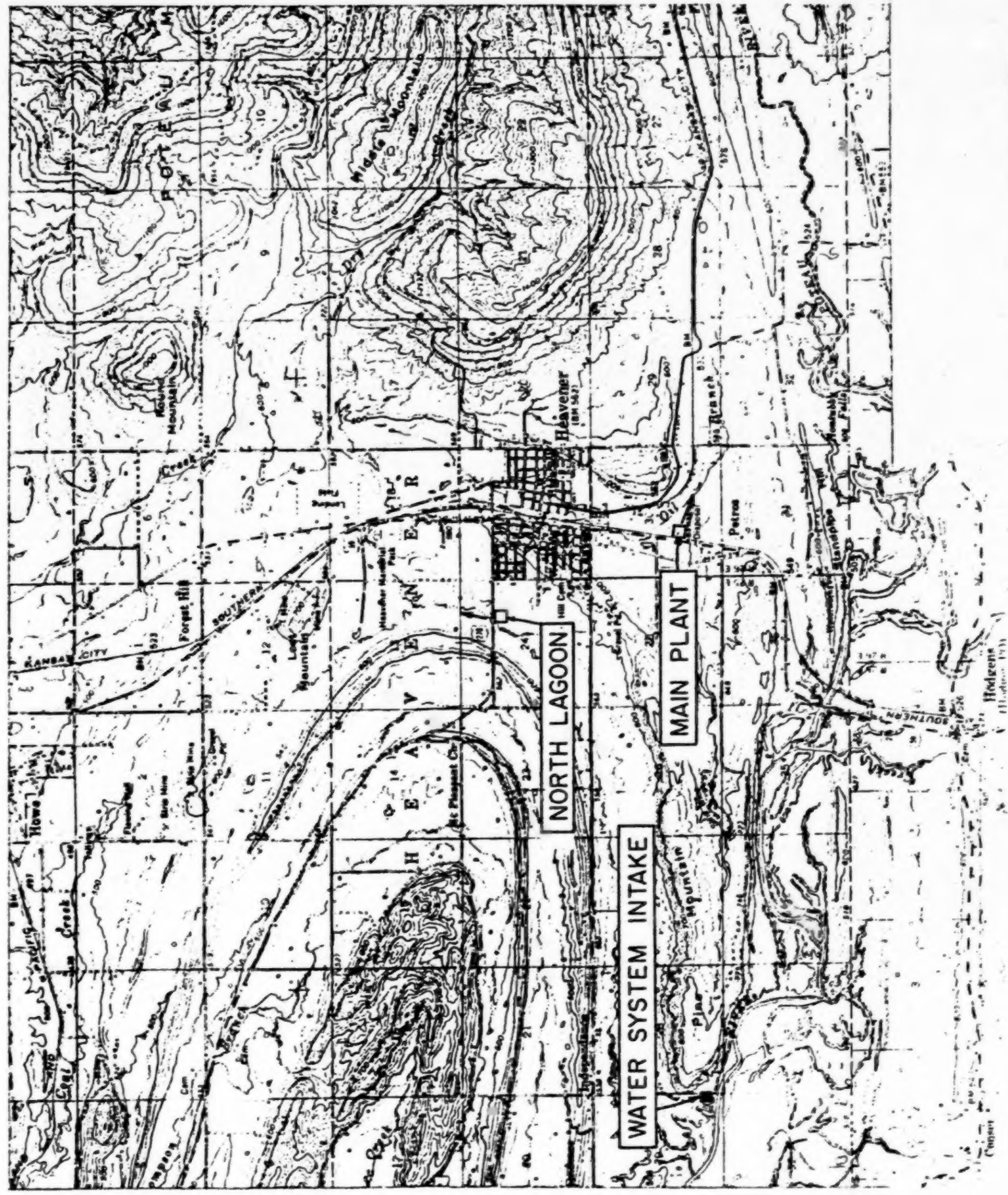

Figure 3.

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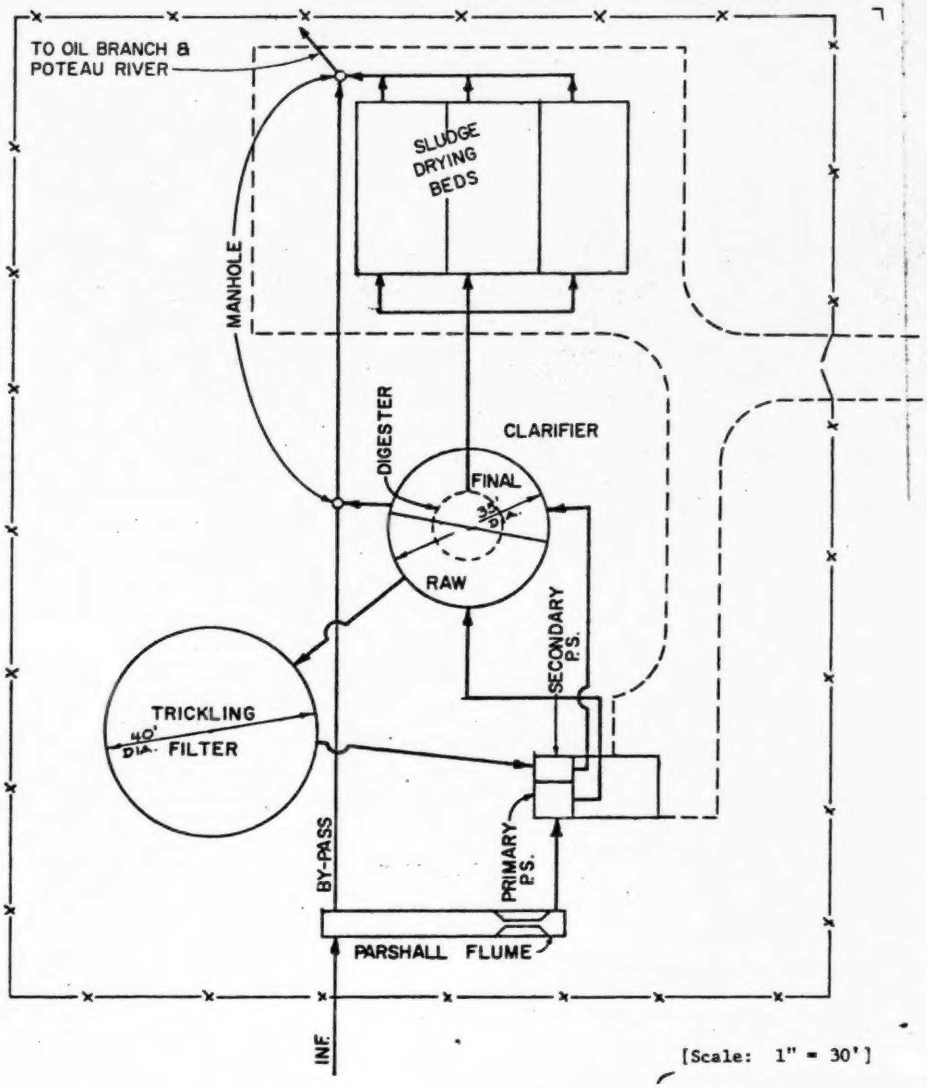

Figure 4. Piping Diagram Existing Treatment Plant South of Town--Heavener, Oklahoma.

	Arkhoma	Oklahoma Pollution Control	Applicant
Population Year 2000	3317 pop.	3317 pop. (A)/2800	3317 (B)
Raw Wasteload Projection	394# /Day	497# /Day	564# /Day
Avg. Daily Flows	0. 189 mgd	0. 2 04 mgd	0. 450 mgd (C)
Per Capita Contribution	57 gpcd	73 gpcd	136 gpcd
Allowable Discharge	7. 4 mg /l	20 mg /l	9. 0 mg /l
Allowable Wasteload	11. 6# /Day	34# /Day	34# /Day
Raw Waste Strength	250 mg /l	292 mg /l	150 mg /l
% Removal Required	97. 1%	93. 2%	94%

(A) Official published population at 2800 for year 2000, later inserted, based on report of Oklahoma Employment Security Commission.

(B) Includes day use and seasonal visitor population, growth outside present city limits, and complementary commercial growth within service area as per Appendix A40 CFR 35E.

(C) Includes 0. 283 mgd dry weather plus 10% industrial contribution plus 0. 139 mgd equalized non-removable I/I from S. S. E. S.

Figure 5. Table of Projected Allowable Waste Discharges.

and land application techniques would be required to give the effluent quality desired. Physical/chemical treatment costs based on EPA's cost comparison curve were far too expensive. Biological/mechanical treatments are known to require very close operator control to produce the effluent limitations desired. Thus, the efficacy of land application came into sharper focus when compared to mechanical or physical/chemical processes capable of achieving similar effluent quality.

The first consideration of any land application scheme is to adequately dispose of the wastewater. In farming and cattle country, the water deficiency is usually most critical in the production of forage grasses for field feeding and small grains and hay crops for winter cattle feed stock. As has been so critically demonstrated this summer, failure of this crop production system causes serious reduction in beef and milk supplies in a region. Utilization of wastewater for hay crop production is reasonably well documented and is being practiced in the more arid parts of the state; but the normal rainfall pattern for LeFlore County will not allow a sufficiently high application rate to generate a cost-effective design. The land area required for the distribution of .45 mgd wastewater is approximately 300 acres. Several tracts of land were available, and feedback from early discussions indicated a general willingness on the part of the farming community to participate in the project. However, few, if any, farmers were willing to sell their farmland outright, and the long-term implications of mandatory utilization contracts discouraged the remainder from the potential disposal site. Further, the removal of such vast land base resources from the tax roles would have had a significant impact on the fiscal resources of the county. It may also be seen that the cost of piping and pumping treated wastewaters over the distances required diminished the cost-effectiveness of this alternative.

Figure 6 depicts the average annual rainfall distribution chart for the State of Oklahoma. Note the proximity of Heavener to the area of maximum average rainfall, 56 inches per year. This is the highest reporting station in Oklahoma and results from its location approximately 10 miles north of Rich Mountain (elevation 2,300 feet). This abrupt topographic feature produces orographic precipitation by rapid lifting and cooling of moisture-laden Gulf Coastal winds.

Spray irrigation is currently being practiced in the Poteau River Valley by private farms, utilizing river water since there are limited groundwater resources. The principal farm crops are peaches, small feed grains of sorghum and milo, and limited plots of soybeans. Away from the river bottoms, the geological age of the surface formations is such that the soil is well weathered and too poor to support intensive cultivation practices without extensive fertilization and soil builders. A substantial amount of soil improvement could be realized by the spray application of wastewater effluents, but the present political constraints and low rate of public acceptance seem to be against the practice.

Geological conditions existing in the western foothills of the Ouachita Mountain Range preclude the use of rapid infiltration systems. It has been noted that there are no significant groundwater systems. The soil systems are very thin and composed of alluvial clays from weathered shale deposits underlain by extensive uplifts of sedimentary formations of shale and sandstone,

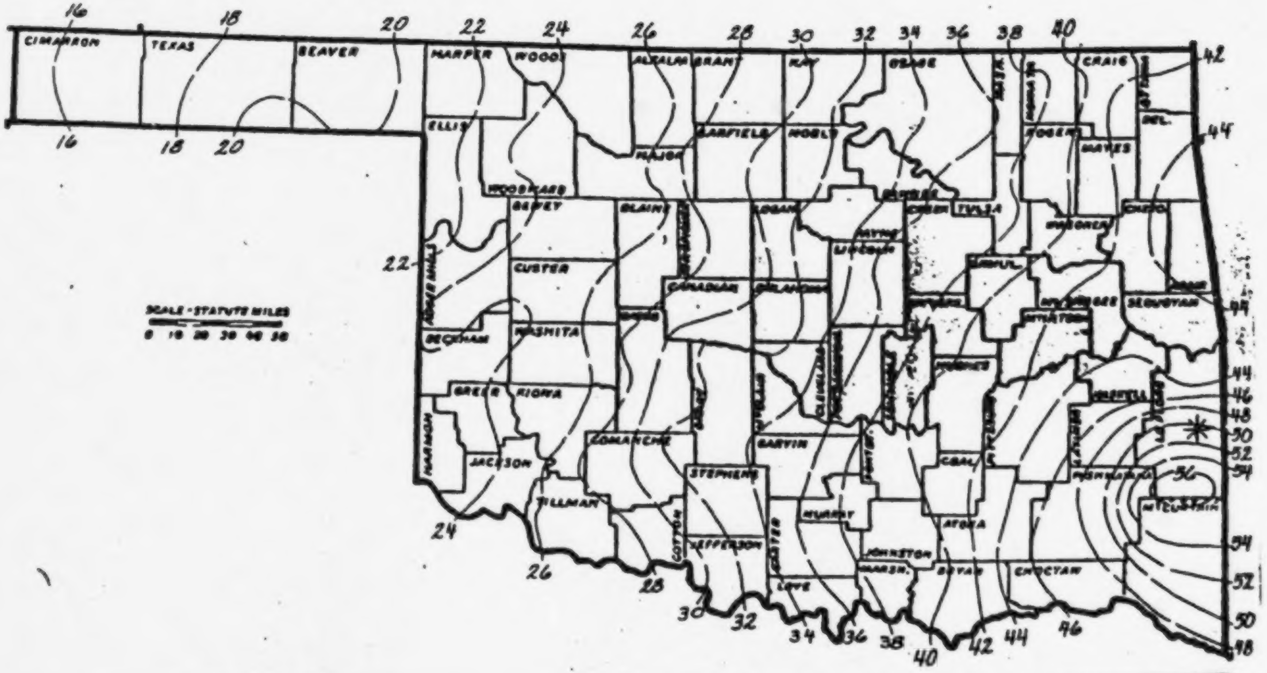

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Figure 6. Rainfall Isopleths--Oklahoma.

known as Atoka, Hartshorne, and McCallister sandstone formations. Groundwater wells generally deliver 1 to 5 gallons per minute and are generally fed by the perched water table. These Pennsylvanian age deposits are totally unsuitable for deep percolation and generate significant excavation costs associated with sewer system construction. These same conditions that are responsible for poor farmland also prohibit extensive reshaping of the land surface and deep excavation for sewers. They support low cultivation and generate somewhat precarious economic conditions in large-scale agricultural exploits.

The overland flow technique is ideally suited where there are thin bedded soils, uniform slopes, low penetration rates, and insufficient soil water systems that could be subject to pollution. The application of waters containing organic matter can significantly contribute to the humus content, productive capability, and residual moisture content, and can provide for an economic stimulus for localized intensive farming practices. A much broader range of money crops can be grown where there is little risk of drought or need for supplemental nutrients. Other papers have adequately dealt with the environmental and intrinsic values of land application systems, but this project originated because of economic constraints. The ideal site configuration was available within a very short distance from the point of accumulated wastewater at a fair price. The present use of the land is for limited cattle grazing; it has a potential of significant upgrading based on the application of wastewater organics and nutrients. The immediate area and region can profit from a successful demonstration of the benefits of overland flow.

The surface soil characteristics are shown in Figure 7 based on the field analysis by the local soil conservation district office. The area of the site is covered by Wister silt loams. Mechanical properties are based on the interpretation of the Soil Conservation Service. Some of the engineering characteristics and classifications will be sufficiently familiar to indicate a very tight plastic uniform clay silt soil. This will require careful attention to prevent washing or erosion and generally indicates the use of flatter slopes. It will be noted that the actual site slopes vary from 1- to 3-percent slopes. Figure 8 represents the actual site and depicts the cross slopes and dimensions in proximity to the application system, infield distribution system, and the effluent collection system. The dimensions are not yet firm but represent the best current data and suggestions for length of flow system. Note the cross field lengths are basically varied to unify detention time within the system. The land is sufficiently uniform on the surface so that only a limited amount of site grading will be accomplished. There will be trenching and ditching to install pipes, spreading systems, receiving trenches, and swales to the discharge monitoring station. The surface will be carefully prepared to permit sheet flow and a few trees removed. The cost estimates leave little room for extensive site preparation. Further work will need to be done in grass and cover crop selection, and efforts are being made to select a marketable product, such as christmas trees or nursery shrubs, to offset system operating costs.

Attention is directed to Figure 9 which shows the detailed water balance calculations for this system. Particular attention is directed to the individual column headings. Sewage flow is supplemented by projected I/I (nonremovable) to produce total wastewater flow, which is converted to acre feet going into storage. The "Water Out" is produced later in the table but [illegible]

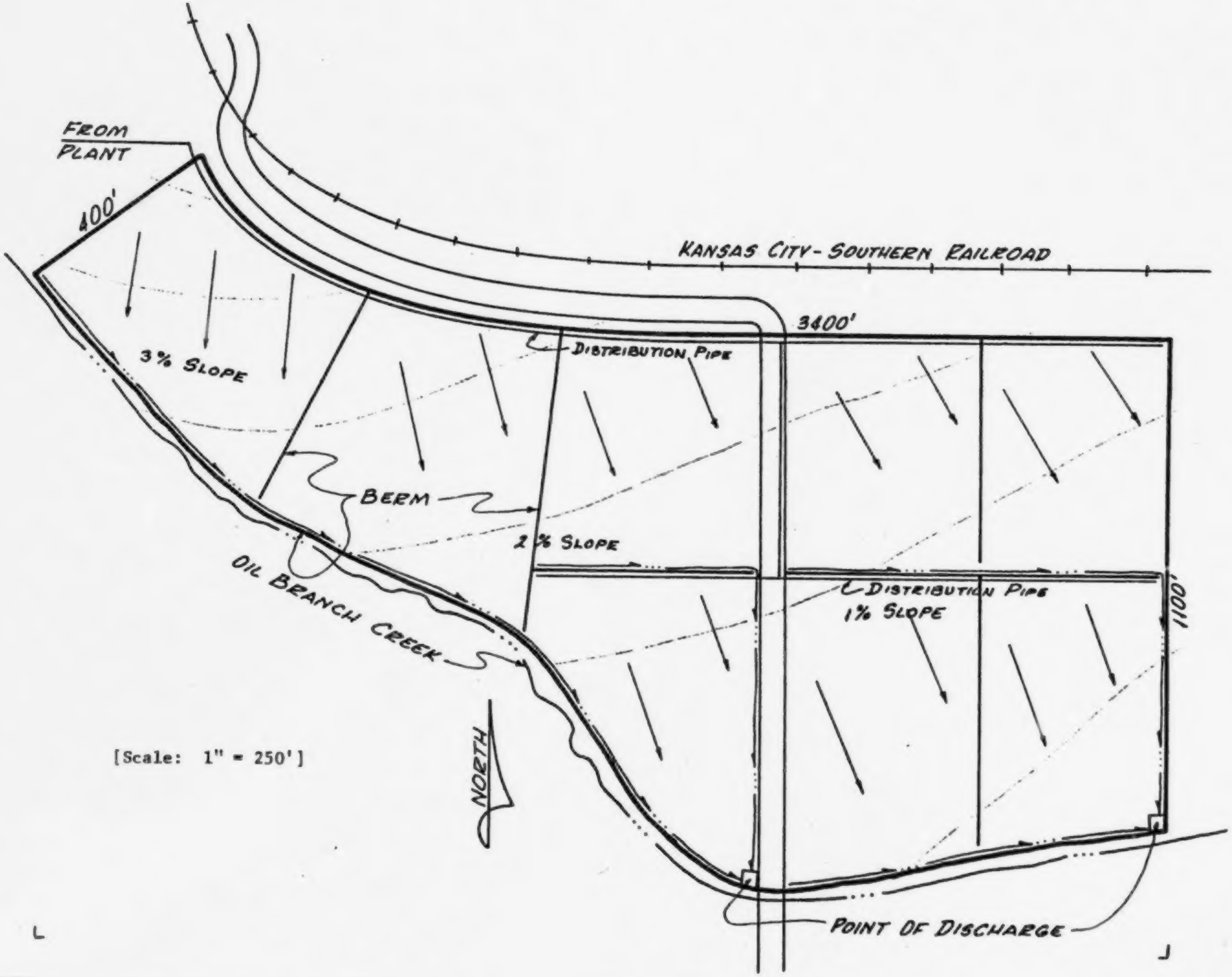
Wister Silt Loam (1% to 3% Slopes)

These are deep moderately well drained, very slowly permeable soils on uplands. The surface layer is brown silt loam. The sub-surface layer is brown silt loam. The upper sub-soil is dark yellowish brown silty clay and the lower sub-soil is mottled yellowish brown and grey silty clay.

Depth	U. S. D. A. Texture	Unified	AASHO	Percent Passing Sieve# 4	10	40	200	Liquid Limit	Plasticity Index
0-15"	SIL	ML, CL, CL-ML	A-4	97-100	97-100	96-100	80-97	22-30	2-10
15-50"	SIC, C, SICL	CL, CH, MH	A-7	95-100	95-100	95-100	93-99	41-65	18-35
50-64"	WB								

Soil perks slowly, has moderate shrink swell potential and is not prone to erode. Natural grasses include big and little blue stem, bermuda, fescue, and other perennials. There is little soil maintenance capacity and will naturally support red cedar (potential for christmas trees). Maximum fiber production is estimated at 5,000# /acre year with normal maintenance and nutrient additions.

Figure 7. Overland Flow Site Soil Characteristics.



[Scale: 1" = 250']

Figure 8. Overland Flow Application Site--Heavener, Oklahoma.

	Sewage Flow MGD	I/I MGD	Total Flow MGD	Water Into Storage Ac. Ft.	Water Out Ac. Ft.	Inventory Ac. Ft.	Evapotranspiration Inches	Run-Off Inches	Total (A) Inches	Precipitation Inches	Eff. & Applied (B) Inches
Jan.	.20	.050	.250	22.96	39	-16.04	1.44	.380	2.07	1.20	12.84
Feb.	.21	.094	.304	27.92	13	-1.12	1.92	.710	2.88	2.21	11.86
Mar.	.24	.214	.454	41.69	16	+24.57	3.36	1.620	5.23	5.31	8.75
Apr.	.27	.261	.531	48.76	24	+49.33	4.80	1.980	7.03	6.26	7.80
May	.32	.101	.427	38.66	50	+38.00	5.28	.540	6.07	2.42	11.34
June	.33	.237	.567	52.07	69	+21.07	5.76	1.84	7.85	5.87	8.53
July	.34	.033	.373	34.25	95	-39.68	6.72	.010	6.98	0.80	13.26
Aug.	.33	.325	.655	60.15	51	-30.53	6.24	2.450	8.94	3.80	6.27
Sept.	.31	.456	.766	70.34	42	-2.19	4.80	3.540	8.59	7.20	2.70
Oct.	.28	.200	.480	44.08	77	-35.11	3.84	1.43	5.52	6.66	9.28
Nov.	.28	.223	.503	46.19	32	-20.92	2.40	1.68	4.33	5.35	8.71
Dec.	.29	.122	.412	37.83	16	+0.91	1.44	.82	2.51	2.92	11.14
	103.30	70.700	.476 (Avg.)	524.90	524	(Note C)	48.00"	17.00"	68.00"	50.00"	112.48"

(A) Includes 0.25"/month deep penetration into bedrock or lateral transport through soil.

(B) This column converted to acre feet and adjusted for freezing days and shown in "Water Out" column.

(C) Maximum storage required is from -39.68 + 49.33 ac. ft. or 89.0 ac. ft. or 102 days at average dry weather design flow.

(D) 100 ac. ft. of water applied on the site (56 acres) represents 21.43 inches of effluent.

Figure 9. Water Balance Calculations.

indicated here for calculation of needed storage. The storage volume of 89 acre-feet is significantly higher than the storage requirements calculated by the EPA algorithm (42 acre-feet), but the remaining I/I must be considered. Further, the State of Oklahoma has a published requirement for 90 days at average design flow. Negotiations are underway to reduce this 124 acre-feet requirement to average dry weather flow or 78 acre-feet. The middle value would represent a reasonable compromise. The next few columns account for evapotranspiration, deep percolation and runoff from rainfall. It is obvious that effluent should not be applied while rainfall is occurring. The average effluent application rate has been further reduced by the projected precipitation value. The resulting application rate is further adjusted by reducing the total amount applied by the number of days the average temperature is less than 32°F. Obviously effluent should not be applied while the ground or foliage is frozen. The resulting effluent application rate is shown in the "Water Out" column in acre-feet per month, with a maximum occurring in June (95 acre-ft.) which represents 20.36 inches of effluent. This maximum will, of course, be adjusted, based on experience in the field after grass cover is established.

The size of sidestream storage seems to generate problems in several sectors. There is justifiable concern about algae production which appears to reduce quality of the overland flow discharge. Some people would encourage the surface discharge of screened raw sewage, to which the author disagrees from a public health standpoint. As a compromise, Heavener proposes an aerated lagoon of only 24 hours detention for preliminary treatment utilizing only 15 hp for complete mixing. This fluctuating level basin will contain sufficient suspended solids and bio-mass to prevent algae formation. Water from sidestream storage would be processed through the pretreatment tank prior to being applied. Experience has shown that such mixing and pretreatment will allow the activated sludge bio-mass to agglomerate or absorb the algae so that they will not escape on the application site. Such an arrangement has already proven highly efficient at Antlers, Oklahoma, where stored waters are processed through activated sludge with excellent TSS results of less than 10 mg/l.

It is also proposed to use fish culture in the sidestream pond to reduce the possibility of excessive odors from bottom sludges during high level conditions. The common carp, or Israeli carp, do an excellent job of plowing the bottom and keeping benthal solids aerated and suspended. This will aid in preventing septic odors from deep ponds and increases the turbidity in pond waters hindering algae formation. It is also quite likely that EPA-sponsored research using the Silver Amur for phytoplankton reduction will be approved for full-scale use by the time this project becomes operational. The topwater minnow Gambusia affinis will be used to control mosquito larvae if there is emergent vegetation. Daphnia Magna will also be encouraged to aid in stripping the phytoplankton from the holding cells. Application of sidestream holding basins for pretreatment and flow equalization has been indicated to be innovative technology, but a final determination is yet to be made for this project.

Attention is directed to Figure 10 which depicts the generalized arrangement of pumping, piping, pretreatment, storage, and land application systems to be utilized. The unique multipurpose pumping station with common dry pit is shown as presently designed.

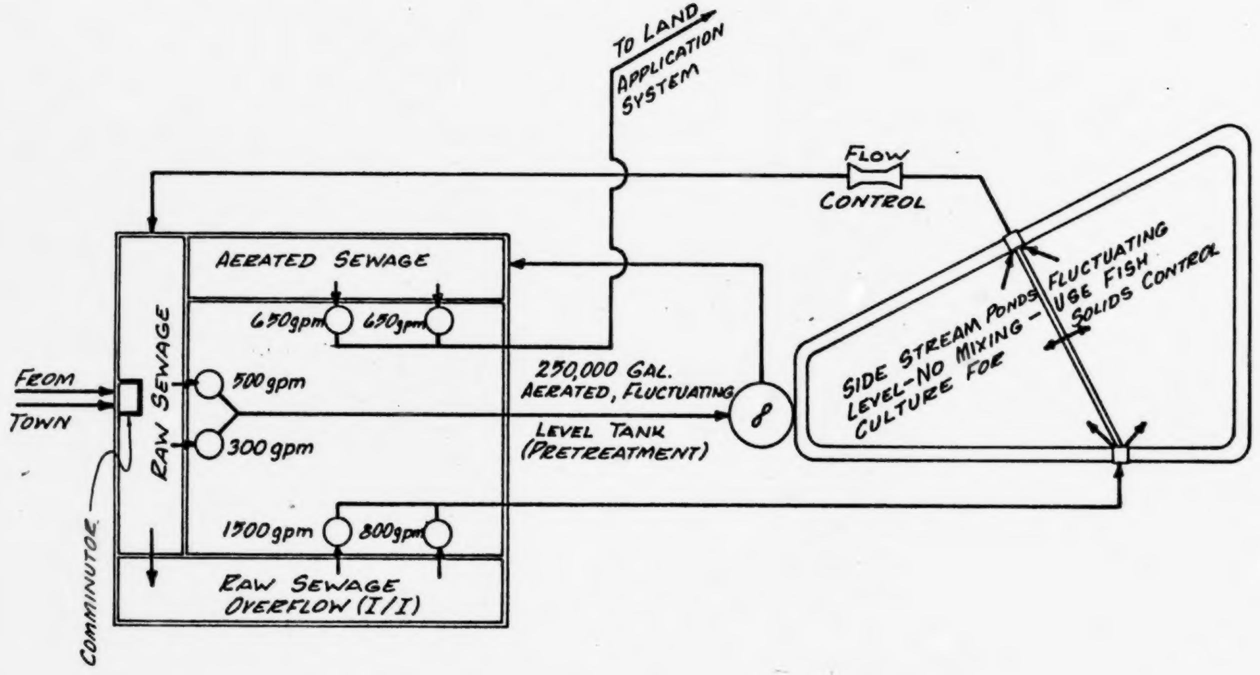


Figure 10. Flow Schematic--Heavener, Oklahoma.

(not to scale)

Now that the whys, wherefores, and hows have been discussed, attention is directed to the comparative cost estimate for various treatment schemes considered applicable to this project as shown in Figure 11. The capital cost estimate for each alternative is based on detailed layout, piping arrangements, equipment costs, tankage and structures, earthwork, land costs, and associated technical fees for implementation. The capital cost recovery figures are used to convert to equivalent annual cost based on the applicable discount rate and various life expectancy for physical elements. Primary power has been estimated for pumping, process machinery, aeration equipment, lighting, fuel for grounds maintenance, and auxillaries. The significance of power will likely be more critical in the future if the 9 percent/year current escalation rate continues. The overland flow scheme is shown to be cost-effective on the basis of these estimates.

COST ELEMENT	BIOLOGICAL DISC	OXIDATION DITCH	AERATED LAGOON	OVERLAND FLOW
Capital Cost	$645,800	$691,800	$709,100	$614,450
Capital Recovery 6-7/8% Various Life Cycles	60,368	64,668	66,285	57,435
Operation & Maintenance	19,150/yr.	19,150	15,800	14,845
Primary Power Consumption	9,050/yr.	15,665	18,530	7,005
TOTAL ANNUALIZED COST	$ 88,568	$ 99,483	$100,605	$ 79,285

NOTE: Only overland flow has the potential for revenue production.

Figure 11. Capitalized Annual Cost Comparison.

Figure 12 depicts the objective ranking of alternatives based on a number of practical, intrinsic, and esthetic values as evaluated by the environment impact assessment. There may be room for disagreement with some of the numerical values which scale up to a perfect ten, but the final result should be the same if applied in a similar circumstance.

	RBC	Rotor Aeration	Aerated Lagoons	Overland Flow
Environmental Effects	7	7	7	9
Capital Outlay	7	6	5	8
Public Acceptability	6	6	7	8
Net Resources & Energy	8	7	6	9
Operational Reliability	5	5	8	7
Income Potential	0	0	2	4
Total (Scale 1 to 10)	5.50	5.17	5.83	7.50

Figure 12. Objective Ranking of Alternatives
(1 - lowest to 10 - highest)

Attention is directed to Figure 13, which depicts the expected interstage range of quality parameters, showing raw sewage, the effluent from the flow equalization basin, and the project application and effluent from the land overland flow system. It will be noted that substantial unit efficiencies are anticipated for the pond to produce an effluent closely akin to ordinary oxidation pond effluent. Note that the removal processes from the land application system are considerably less stressed by the application of equalized and pretreated waters.

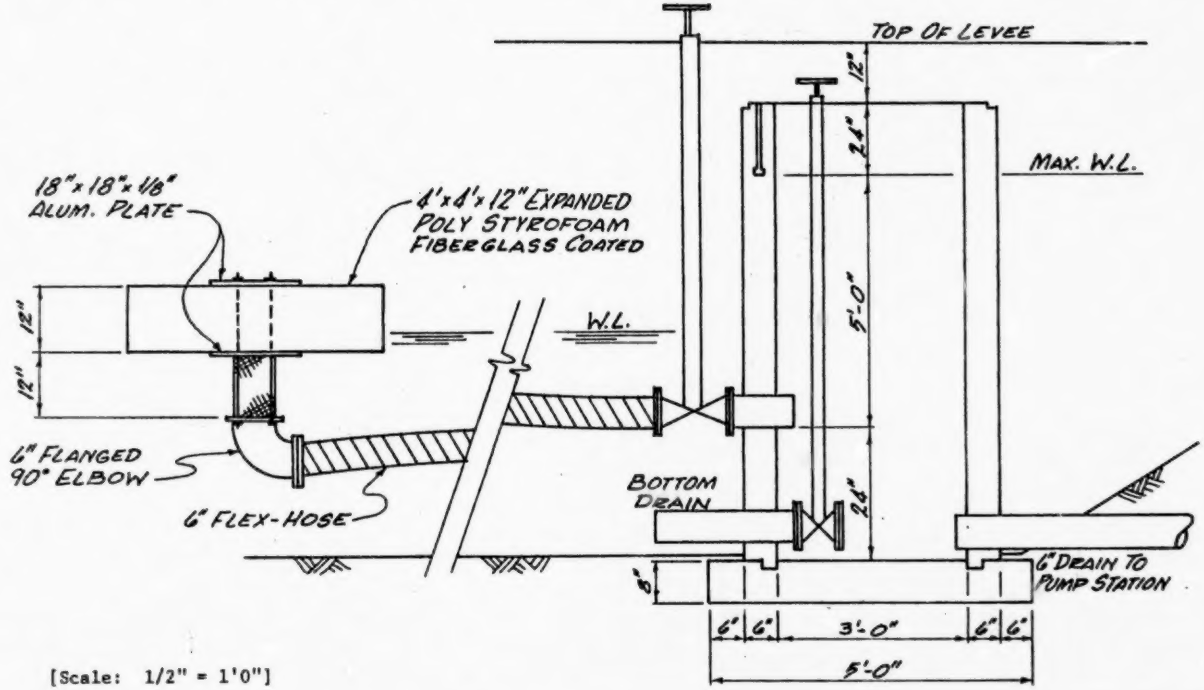
One particular device will be credited with providing a good quality water for land application. The arrangement depicted in Figure 14 is being used in several facilities to allow fluctuating water levels in ponds. With this simple device the 2-foot minimum is preserved; fish, turtles, and floating solids are kept in the pond; and there is little change in flow with level fluctuations. This device will regulate the flow out of the sidestream basin to be blended with below-average domestic flow in dry weather.

Dr. Ross McKinney has been credited with the statement indicating that adding a treatment process to an oxidation pond is like putting a jet engine on a box kite. In rebuttal, it is contended that the overland flow scheme may be the simplest jet engine yet developed.

It is hoped that this paper will depict how the investigators arrived at a pragmatic solution to meet the economic and environmental situation presented by the community. It is hoped that more data will be available after two years of operation when many factors have been more clearly defined. Several agency approvals are yet to be secured, and it is possible that the project

	Raw Sewage (Dry Weather)	Combined Flow (Wet Weather)	F. E. Basin	Overland Flow	System Effluent
BOD mg/l	200-300	100-150	40-70	60-150	10-20
Settleable Solids ml/l	6-15	3-10	1-3	10-30	1
Suspended Solids mg/l	200-300	100-400	30-100	100-800	10-30
Dissolved Solids mg/l	250-500	100-300	100-300	100-400	80-300
Total Solids mg/l	450-800	200-700	130-400	200-1200	100-330
Dissolved Oxygen mg/l	0-3	0-8	4-18	6-12	6-12
Phosphorous mg/l	5-12	4-8	2-8	2-10	0-4
Nitrogen mg/l	20-40	5-20	5-30	5-30	2-10
Fecal Coliform Col. /100ml	10^5-10^7	10^4-10^7	10^4-10^6	10^3-10^5	10^2-10^4
Oil & Grease mg/l	2-40	2-40	2-10	2-20	2-10
pH s.u.	5.0-10	5.0-10	6.0-11	6-10	6-9

Figure 13. Interstage Physical/Biological Parameters.



[Scale: 1/2" = 1'0"]

Figure 14. Outlet Box Detail--Heavener, Oklahoma.

may not be operational before Spring 1983. In the meantime, the quest for better design data and the not-so-obvious influencing factors should continue. This investigator has two other projects under way which may result in land application to irrigate a pinetree plantation and a soybean farm or perhaps rice fields. It is obvious that the technique of land application has particularly beneficial economics in the proper setting and provides one more alternative to meeting water quality criteria.

Question (by Dr. Robert Smith): I wasn't quite clear on what odor-control measures you were planning for the side stream pond. Would you please clarify that?

Response (by Mr. Alford): Those of you who are familiar with ancient Chinese fish culture will remember that there are several carps which have very specific purposes in night soil bottom feeding; the common carp and the Israeli carp are two species of bottom feeders. They plough the benthal deposits, resuspend the settled solids, redissolve and resuspend the nutrients, and basically improve the quality of the bottom deposits so that they do not generate quite as much hydrogen sulphide. For deeper ponds, about 5, 6, or 7 feet deep, a combination of the top-water-feeding carp, and the bottom-feeders are two natural control processes which we would attempt to use.

PB82-194440

Overland Flow Design Example

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INTRODUCTION

One factor which is typical of all land treatment system designs is the dependence on a number of interrelated factors, including wastewater characteristics, discharge limitations, site conditions, and climatic factors. A proper design represents an interdisciplinary approach which involves knowledge of not only engineering principles but also some experience in the areas of soils, agronomy, hydrogeology, biology, and climatology.

Since every project and every site represents a different set of conditions, a rigid set of design criteria is not practical, nor desirable. The design limitations must be flexible enough to allow for the most efficient, cost-effective utilization of the site while still meeting the overall project objectives and discharge requirements. Research and experience with the overland flow process have produced certain design guidelines which allow this flexibility but which also place limits on various design parameters. By staying within these limits, the designer will be able to adapt the system to the site conditions in an efficient manner while at the same time achieving an acceptable level of treatment.

The purpose of this design example is to outline a logical approach to the design of an overland flow treatment system and to set forth the various guidelines which should be followed during the design stage. This example will represent more of a preliminary rather than final design, since it will not go into the details of designing many of the system components such as pipelines, storage lagoons, and preapplication treatment equipment.

It is important to note that, at the present time, there is no precise mathematic model based on treatment kinetics for determining loading rates and terrace design. The Cold Regions Research and Engineering Laboratory in Hanover, NH has recently developed a design procedure based on hydraulic detention time, and the University of California at Davis is currently conducting a research project aimed at developing a functional relationship between design parameters and treatment performance. There is an excellent chance that these projects will eventually result in a universally applicable design procedure. However, none of the work to date has been projected to a full-scale operating system. Therefore, the design procedure presented in this example does not incorporate this developing technology. The design methods used are patterned after the design of currently operating, full-scale, successful systems.

STATEMENT OF THE PROBLEM

A small, rural community in the eastern United States has an existing wastewater treatment system which is currently not meeting its discharge permit. The community has a 20-year design wastewater flow projection of 0.3 MGD. The objective is to provide the community with a wastewater treatment system capable of meeting the discharge requirements.

DESIGN DATA

Wastewater Characteristics

One of the first steps in determining the feasibility of land treatment is to determine the raw wastewater characteristics. The characteristics will determine whether the waste is amenable to land treatment and will also have a bearing on the degree of preapplication treatment required as well as the loading rates on the land treatment system. For municipal wastewaters, any industrial input is especially important. The community in this example is a totally residential community with no industrial wastewater flows. The 20-year design flowrate is 0.3 MGD. The raw wastewater characteristics are typical of domestic sewage, as outlined in Table 1. Although not listed in Table 1, the concentrations of trace elements are within the typical range for municipal wastewaters.

TABLE 1

RAW WASTEWATER CHARACTERISTICS
(mg/l)

BOD_5	200
Suspended Solids	200
Total nitrogen, as N	40
Ammonia as N	25
Organic as N	15
Total phosphorus, as P	10

Discharge Limitations

The existing wastewater treatment system currently discharges into a small receiving stream which flows several miles before entering a larger river. Any new treatment system which generates a point source discharge will also have to discharge into the same receiving stream. The State regulatory agency has imposed the following limitations: BOD_5, 20 mg/l; suspended solids, 20 mg/l; fecal coliform, 200 MPN/100 ml.

Current Treatment System

When designing a land treatment system, consideration should always be given to utilizing the existing wastewater treatment system for preapplication treatment. It is often more cost-effective to do so if the existing system has sufficient capacity and is physically and mechanically sound. In this case, however, the existing system is a 30-year old treatment system which is in very poor physical and mechanical condition. A study of what is required to rehabilitate the old system in order for it to provide adequate treatment, or even preapplication treatment prior to overland flow, concluded that it would be more cost-effective to abandon the existing system and to build a new preapplication treatment system.

PRELIMINARY SITE INVESTIGATION

A preliminary investigation of available sites must be made as early as possible. This should include a determination of what land is available. If more than one site is available, each must be compared relative to adequate size, location, cost, and site characteristics. The site conditions at each location generally determine whether the site can be used for land treatment and, if so, which type of land treatment is best suited for the site conditions. The U.S. Soil Conservation Service county soil surveys will usually give the designer a good idea of what type of soils are present on the site and what type of land treatment system is most applicable. In addition, however, it is recommended that a series of shallow borings or backhoe pits should be made to confirm the general soils mapping. In doing so, the presence and extent of shallow groundwater or rock can also be determined if either exists. If present to any significant degree, either could interfere with the development of a land treatment system.

The vegetative cover and the topography of the site are also important. If the soil conditions favor overland flow, the existing vegetation will have to be removed, and knowledge of what exists will help to determine the cost of clearing the site. In the preliminary investigation, a U.S. Geological Survey map of the site usually provides sufficient topographical information. For overland flow projects, a more thorough contour survey of the site will be required prior to final design, but it is not necessary to develop one at this stage.

In this example, a preliminary site investigation determined that approximately 100 acres of land near the existing wastewater treatment system is available. The site has a gentle slope and drains naturally into the same small stream which receives the treated effluent from the existing treatment system. A large portion of the site is wooded with pines, hardwoods, and thick undergrowth. The soils consist of a sandy loam surface soil underlain at shallow depths with red and brown clay having limited permeability. This was confirmed by soil borings taken by a soil scientist. The presence of the clay subsoil will impose significant restrictions on the use of this site for slow rate irrigation. Therefore, it appears that the overland flow process is best suited for the site. To confirm this, it may be necessary to develop a similar design outline for a slow rate irrigation system on the same site and then compare costs and benefits to the overland flow design. It will be assumed here that this has been done and that the comparison favors overland flow.

PREAPPLICATION TREATMENT

As discussed previously, a review of the existing treatment plant resulted in the conclusion that it should be abandoned and replaced with a new preapplication treatment system. The preapplication treatment approach most universally accepted by State regulatory agencies is to provide some form of biological treatment prior to land application. Two satisfactory alternatives are the use of either an oxidation pond or an aerated lagoon. The oxidation pond will require the construction of a larger pond than the aerated lagoon will, but it will not require forced aeration and the resultant energy costs. It is necessary to conduct a cost-effectiveness analysis of the various preapplication treatment alternatives available and to choose a system on that basis.

The method of preapplication treatment chosen for this project is a facultative lagoon utilizing surface aerators, preceded by a bar screen and comminutor. It is not necessary to provide a high level of treatment in the lagoon system prior to applying the wastewater to the land. Therefore, a 50 percent BOD reduction is assumed in the design. This will result in an effluent BOD concentration of 100 mg/l which will be applied to the overland flow system. The details of calculating the size of the facultative lagoon and the horsepower requirements will not be discussed here.

HYDRAULIC LOADING

The hydraulic loading rate chosen for this project for winter operation is 0.57 inches/day (4 inches/week). The reasoning for this selection is as follows:

1. The BOD of the applied wastewater is expected to be 100 mg/l while the stream discharge requirement is 20 mg/l. During continuous periods of nonfreezing temperatures, the overland flow system is expected to produce an effluent with a BOD of less than 10 mg/l. During intermittent operation during winter, the proposed loading rates will be low enough to achieve the desired final effluent quality. Higher winter loading rates are not recommended since they might place too much stress on the system and result in inferior effluent quality.

2. The project is located in a relatively mild climate zone where, although freezing temperatures are common, prolonged periods of subfreezing temperatures and deep frost lines in the soil are not usually experienced. Therefore, it is not necessary to use lower loading rates.

For both design and operating purposes, it is assumed that the winter loading rate (0.57 inches/day) will be in effect during the winter months and will stay in effect for a certain time after the last day requiring storage. The operating decision regarding when to release wastewater from storage for final treatment will be based on both climatic conditions and daily operating performance. If the weather continues to be cold and damp during the first several weeks after storage ceases, and if the final effluent quality is close to the discharge requirement, it is best to continue at the winter loading rate of 0.57 inches/day and not to treat stored wastewater. As effluent quality improves, wastewater can be released from storage. The rate at which it is released should also be based on current operating conditions, beginning slowly and building to the point where the stored water is released at a rate equal to one-half the design flowrate, for a combined total hydraulic loading rate of 0.86 inches/day. Periods of unusually warm, dry weather when water is still being held in storage will probably allow even higher loadings. Final effluent quality will be the most important factor in determining daily loading rates when releasing stored wastewater.

It is not necessary to have additional land or to store wastewater during the few days of each year that the vegetation is cut and harvested. However, since storage is available, it will be quite practical to route all wastewater to storage for a few days to allow for drying of the slopes and cutting of the vegetation.

STORAGE

To determine the amount of storage required for cold weather operation, it is necessary to review the past weather records. One method for calculating storage is to review the past data on air temperatures and to base the storage requirements on the following limitations. Assume that wastewater application will proceed on a regular basis until the maximum and minimum daily temperatures fall below 40°F and 25°F, respectively, at which time wastewater will be stored. When the maximum temperature is below 40°F, but the minimum is equal to or above 25°F, application will occur for 1/2 day and wastewater will be stored for 1/2 day. Application will resume when the maximum temperature rises to 40°F or above. The 25°F limit is used instead of 32°F because experience with full-scale operating systems has shown that high levels of treatment continue to be achieved at air temperatures below 32°F. The 40°F limit for resuming application has also been found by experience to be sufficient for the system to "thaw out" after having been in the storage mode.

A second alternative for calculating storage is to establish operating limits based on soil temperatures rather than air temperatures. However, existing climatic data for any particular site almost always include air temperatures but rarely soil temperatures. Therefore, attempting to calculate storage based on soil temperature data is impractical in most cases.

Climatic data obtained from an official weather station near any project location are usually available. This information can be ordered from the National Climatic Center in Asheville, North Carolina. At least 20 years of data using the previously outlined air temperature limitations should be reviewed to determine the critical year, or the year which would have required the most storage. The data for this particular year are listed in Table 2, which shows a storage requirement of 44 days, or 13.2 million gallons, at the design flow of 0.3 MGD.

TABLE 2

STORAGE REQUIREMENTS

Month	Storage Days	Application Days
November	0	30
December	15.5	15.5
January	14.5	16.5
February	14.0	14.0
March	0	31
	44.0	

LAND AREA REQUIRED

Once having established the hydraulic loading rate, the amount of land required can be calculated. For a daily wastewater flow of 0.3 MGD and a loading rate of 4 inches/week, approximately 20 wetted acres will be needed as shown by the following calculation:

$$\frac{2{,}100{,}000 \text{ gal/wk}}{27{,}154 \text{ gal/A-in.} \times 4 \text{ in/wk}} = 19.3 \text{ wetted acres}$$

Additional land will be required for collection ditches, access roads, and small areas which do not fit economically into the grading plan. This usually amounts to about 20% of the wetted area, which, in this case, amounts to 4 acres. The land required for the preapplication treatment system and the storage pond will amount to another 10 acres. Finally, the land required for buffer zones must be added. The size of buffer zone is dependent on local and State regulations. However, based on experience to date, a 100-foot buffer zone is reasonable, particularly if the application site is isolated from the neighboring dwellings or is heavily wooded. The actual land area will be dependent on the shape of the site; however, assuming a square application area of 34 acres (20 wetted plus 14 for ditches, storage, etc.) and a perimeter buffer zone of 100 feet, the land required for the buffer zone will be approximately 13 acres, resulting in a total land requirement of 47 acres.

ADDITIONAL SITE INVESTIGATION

Once the amount of land required has been determined, it is necessary to obtain additional site information. The preliminary site investigation should have been sufficient to categorize soil types and the presence of rock or groundwater to depths of 8 to 10 feet. For monitoring purposes, however, it is necessary to perform several soil borings to determine the depth to groundwater. A minimum of three such borings will also allow the determination of velocity and direction of groundwater movement. These borings can eventually be made into permanent groundwater monitoring wells. It is important to have at least one monitoring well located in such a way as to serve as a background well and at least two wells down-gradient from the treatment site.

A detailed contour survey and property plan must also be run on the proposed application site. This should result in a contour map with one-foot contour intervals, which will be used to develop the final grading plan and arrangement of the individual overland flow terraces.

DISTRIBUTION SYSTEM

Prior to designing the overland flow terraces, it is necessary to determine the type of distribution system which will be used. Although there are a number of options available, the method chosen here is sprinkler irrigation. This type of distribution system has the advantage of applying the wastewater over a much larger area than low pressure systems and in doing so minimizes the potential build-up of solids at the distribution point. One type of sprinkler which has been found effective is an impact sprinkler with a 1/4-inch nozzle opening and a discharge capacity of approximately 20 GPM at 60 psi. These sprinklers can be supplied by an underground PVC force main with individual lateral lines running across each terrace, approximately 65 feet from the top of the slope. At 80 feet intervals along the lateral line, riser takeoffs will be located and will protrude above grade. The sprinklers will be located on top of each riser.

TERRACE DESIGN

The size and slope of the individual overland flow terraces are dependent on the method of wastewater application and the existing shape and topography of the site. Utilizing the sprinkler application method described above, optimum terrace lengths from top to bottom of slope range between 180 and 200 feet. The degree of each slope should range between 2 to 8 percent. The cross-slope dimension of each terrace and the number of individual terraces are governed chiefly by the shape and topography of the site. Using the existing contour map, it is necessary to run a balanced cut-and-fill exercise of the site, attempting to establish the most economical grading plan. It is not necessary to have all terraces alike (size, slope, etc.). It is necessary, however, for each slope to be between 2 and 8 percent and 180 and 200 feet long. The steeper slopes (6 to 8%) should have the 200 feet lengths while the lower slopes (2 to 4%) can be 180 feet long.

VEGETATION

Ideally, the cover crop chosen should be a water tolerant species of grass, one which is capable of accepting the high hydraulic loading rates imposed by the wastewater application. Additionally, the vegetation should also have a high nutrient uptake and a long growing season. Reed canary grass is a crop which combines all these qualities and which has been shown to be successful in most areas of the country. Bermuda is also capable of providing a good cover crop but it is limited to the warmer climates. Since it is generally best to plant a mixture of grasses, the ones recommended for this project are reed canary, bermuda, fescue, and rye. It is also strongly recommended that the designer discuss the project with a local county agricultural agent and soil conservationist. They may suggest a grass species particularly adapted to the local area which might do exceptionally well under the imposed conditions. If so, that species should be included as part of the mix.

DISINFECTION

From both a cost and effectiveness standpoint, disinfection of the treated effluent prior to stream discharge is recommended. As is the case with most wastewater treatment systems, chlorination is still one of the simplest and most economical methods of disinfection. The specific design of the chlorination system will not be discussed in detail. However, it is generally sufficient to design it for the full design flow. During dry weather, due to evapotranspiration and limited soil infiltration, the effluent runoff volume will be less than the applied wastewater flow. Therefore, if the chlorination system is designed for the full design flow, it will be capable of also handling a certain volume of storm runoff. Although storm runoff flows greater than the design flow will create additional volume, the dilution effect is generally sufficient to maintain the fecal coliform concentration within limits.

MONITORING SYSTEMS

Since the wastewater being treated is typical domestic sewage, there is no need to monitor the raw or preapplication treated wastewater on a frequent basis. It is recommended that the incoming flow be measured daily, however. The type of effluent monitoring required for an overland flow system is an open channel flow measuring device (Parshall flume, weir, etc.) with a continuous flow recorder attached. In addition, an automatic sampler is required for collecting composite samples at the frequency outlined in the operating permit. Also, at least three groundwater monitoring wells should be installed, as discussed previously.

Question (by Mr. Rick Hunt): How long a slope would you recommend beyond the spray pattern of the impact sprinklers?

Response (by Mr. Deemer): I would recommend 45 to 55 feet beyond the wetted area of the sprinkler.

Question (by Mr. Jim Alexander): When determining your total field area requirement, how much extra land do you allow for harvesting?

Response (by Mr. Deemer): We do not provide any additional land for harvesting purposes. One option is to use the storage, provided storage is available. The question of potential algae problems from summer storage has already been discussed, and I prefer another option.

We recognize that the grass harvesting time is in the warmer months, when the system is capable of accepting higher waste loads for short periods of time. It is possible to harvest one section while the full waste load is applied over the rest of the system at a somewhat higher rate.

Question (by Mr. Tom Wright, U.S. Environmental Protection Agency, Region VI, Dallas, TX): How do you arrive at the 2- to 8-percent slope range?

Response (by Mr. Deemer): The 2- to 8-percent slope range was determined via research results and practical application.

Additional Comments (by Mr. Thomas): The lower value of 2 percent is set by the physical difficulty of getting a good slope at less than 2 percent to avoid ponding. Long-term ponding causes problems with insect breeding.

Slopes greater than 8 percent cause difficulties in maintenance after the system is working. This is due to possible erosion.

Question (by Mr. Jerry McDermott): Do you ever skim the sod off and put it back after you shape the slopes?

Response (by Mr. Deemer): On a full-scale operation it is generally not cost-effective or practical. The extra effort required to properly remove and preserve the sod is really not worth the effort.

PB82-194457

Summary and Closing Remarks

Curtis Harlin

We have come to the point in the program for summary and closing remarks. There is an entire hour set aside, to be shared by Dick Thomas and myself. We don't have many summarizing and closing remarks to make, so after a few remarks by Dick and me, we will show the film Water Passages.

Dick and I are going to divide our summary: I will be summarizing the presentations that dealt with research and development aspects, and Dick will be talking about the policy regulations, case histories, and design aspects of the presentations.

We heard reports by several researchers on specific projects--the Ada project, Utica project, Pauls Valley, Easley, Davis, and so on. The objectives of these studies included determination of loading rates, optimizing loading schedules and cycles, treatment efficiencies, and several of them included different methods of applying wastewater to the land.

Most of the conclusions presented confirm that properly designed and operated overland flow systems could achieve a high degree of treatment, at least equal to secondary treatment, even when raw wastewater was applied to the plots. The results indicated that the less the preapplication treatment, generally, the greater the treatment efficiency.

This is particularly apparent in nitrogen removal, as I believe you will recall. Some of the shortcomings that were pointed out in these reports on overland flow were that without taking special measures they are poor actors as far as phosphorus removal is concerned. At least in a few presentations, it was reported that additions of alum were applied, which did increase the phosphorus removal to very high levels.

Also, it was reported that overland flow is not too efficient in suspended solids removal when the solids are certain algal forms. Some researchers indicated that there were high numbers of coliform in the runoff on the overland flow plots. Several types of application systems were described. These included rotating booms with sprinklers on the ends; fixed risers with sprinklers; different types of surface applicators, such as troughs, gated-pipe, continuous-pipe with orifice discharges; and so on. The results from these studies indicate that there was apparently no difference in the treatment results related to the type of application system that was used.

Systems were described that were constructed with different degrees of slope, ranging from 2 to 8 percent. The results that were reported indicated that there was virtually no difference in treatment results depending on slope within this range.

It was also reported that overland flow can effectively remove organics, and that the BOD concentrations in the runoff can be expected to be consistently 10 milligrams per liter or less.

Limited results were reported on removal of trace organics, and these limited data did indicate that overland flow could be effective in dealing with those substances that had been studied. Much additional work still needs to be done in this area.

Because of design and operating features of overland flow, we heard that many health concerns commonly associated with land treatment systems were minimized or even eliminated. The heavy, impermeable soil types that are used for overland flow generally preclude contamination of the groundwater, which is the primary concern with all land treatment systems.

Application systems in use were described that can eliminate the problems of aerosols, which is another common concern in land treatment facilities. Because the overland flow system is a point discharge system, it does make disinfection very easy and effective when this is required.

In summary, I would say that while there are still unanswered questions, and some of the results reported here might appear to conflict, I think that we can confidently say that with the presently available information, the overland flow process can be designed to achieve a high degree of treatment at a very competitive cost.

In fact, we may well find in years to come, as our data base grows, that the systems we are designing now are designed very conservatively. Of course, since I am a researcher, I would be expected to say that research and evaluation should continue to identify further problems, to identify the capabilities of these systems more accurately, and to refine the operating and design criteria.

At this time, I would like to compliment all of our speakers on their excellent presentations and to give a special vote of thanks to our two conference coordinators. I also want to commend and compliment all of you attendees for giving the high degree of interest that you've shown, and for the fact that the sessions have been so well attended. I'm sure that all questions have not been answered, but I hope that all of us now have a higher degree of confidence in the overland flow process capabilities than we did before. Thank you very much.

PB82-194465

Summary and Closing Remarks

Richard E. Thomas

We are gaining substantially in our knowledge, in understanding and acceptance, and we are beginning to use overland flow.

A year ago I attended a workshop at Easley, and I can say that my level of confidence has been greatly expanded in the one-year interval. I expect that to continue and I will do my part to make sure that information exchange workshops are held frequently.

I see a need for change in the emphasis on research to obtain more specific information, such as details about mass loading, suspended solids removal, trace organics removal, the issue on coliform, etc. We need more specific research that can lead to a broader base of design than the experience design that we currently utilize on the hydraulic load.

There always will be one more question that needs an answer, at least in the area of research. But I will leave this seminar with more confidence that we can continue to encourage the use of overland flow through the Construction Grants Program.

In the area of guidance, there were more States than I realized that have some language in their guidance pertaining to overland flow, but, more importantly, I recognize that we are in a state of change. The States have very heavy burdens of keeping pace with technology development, and I feel that they need more assistance in working on their guidance. I will try to facilitate this process.

Facility planning is more difficult for new technologies. When you are dealing with an innovative, alternative-type technology there are many roadblocks that encourage you to work as a team. In your discussion of the issues, try to resolve them as you go along rather than get to the end of the planning process on your own initiative, and then go to the State agency and find the staff saying "We just do not see that; we are not comfortable with that."

I will go back to Washington with a message that I would like to organize a mini-seminar series on overland flow systems about a year from now. We might change the emphasis to give a summary of research advances while focusing more on design and construction. We should be able to discuss construction and some actual operation.

As far as the assistance that EPA can provide, we do have overland treatment coordinators in each Region as well as I&A coordinators. We have the Task Force. We are looking at the functions of all three of these groups of people and expect there will be some changes and expansion. For example, a possible role for the Task Force, which is now located at Ada, would be to become a part of a National assistance function. We could link them more closely with Regional and State coordinators to have a National network of people readily available to provide technical assistance in all areas. The Task Force, as a pilot program in Regions VI and VII, has been successful, and we do look quite strongly towards the expansion of that concept of assistance.

With that, I will move to the introduction of the film *Water Passages*, which features basic land treatment, water reuse, and conservation-type systems. It is structured for public television. There are copies available through the Land Treatment Task Force and from all EPA Regional Offices. The film is a small part of the reservoir of information that they have available for loan to provide technical information on developing technologies.